Study on the database structure of commercial buildings for reduction of energy consumption

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Master's Thesis

STUDY ON THE DATABASE STRUCTURE OF COMMERCIAL BUILDINGS FOR REDUCTION OF ENERGY CONSUMPTION

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Graduate School of Marine Science and Technology
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Contents

1. Introduction

1.1 Background

Owing to global warming problem in recent years, the importance of energy saving in commercial section is increasing. According to the IPCC Fourth Assessment Report (2007), there is large potential for the mitigation of CO_2 emissions from buildings in the worldwide. In Japan, energy consumption and CO_2 emission by commercial buildings has increased rapidly in several decades. Therefore, measures of improving energy efficiency of commercial buildings are required at present.

Figure1.1-1 shows the energy consumption change in Japan divided into 3 category; transportation sector, civilian sector and industrial sector from 1965 to 2007. Energy consumption of industrial sector generally continue to be flat in this 20 year because of development of energy saving technology after two oil shocks in 1970s. However, energy consumption of transportation and civilian sector has been increased at the same time.

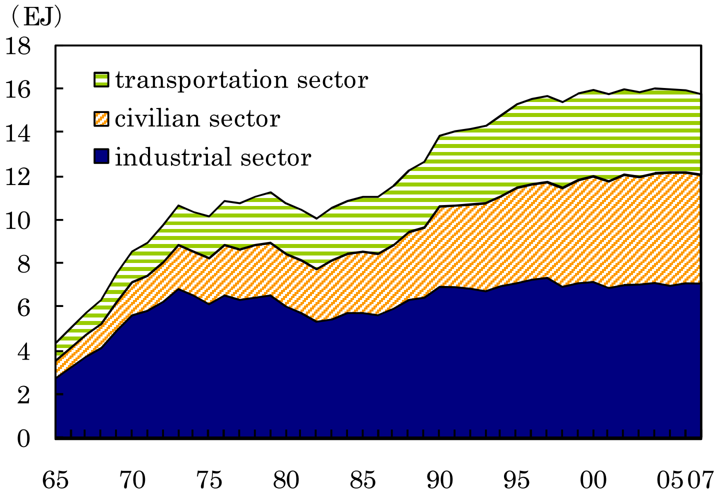


Figure1.1-1 Domestic energy supply from 1965 to 2007

Source; Agency for Natural Resources and Energy (2009) "Energy White Paper"

Figure1.1-2 shows the energy consumption change of civilian sector. Civilian sector is divided into two sectors; commercial sector and residential sector. Especially commercial sector has been increased rapidly. Reasons include the increase of commercial buildings and facilities such as air-conditioning system and PC etc. According to "Building Stock Estimation", population of domestic commercial buildings exceeds 10 million in 2000.

Under this situation, some legal restrictions for energy-saving of buildings are enhanced recently. "Law Regarding the Regulation of Energy Use" was revised several times during 2000s in order to improve energy efficiency measures of commercial sector. Latest version came into force on April 2009 and following points were introduced; 1) order for improvement against buildings which energy-saving measures is incomplete, 2) introducing obligated notification system to small buildings (from 300m² to 2000 m² floor space). In the future, it is considered that more effective measures will be introduced.

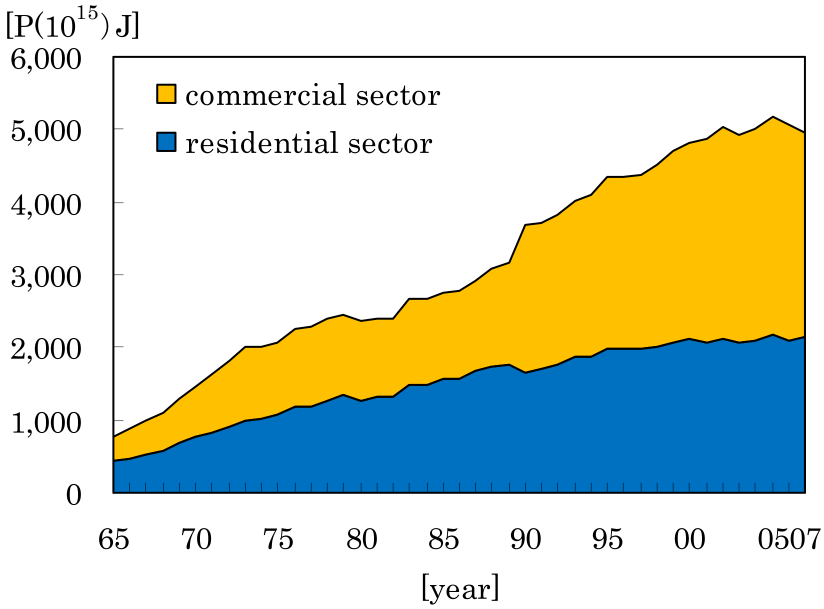


Figure1.1-2 Energy supply of civilian sector 1965 to 2007
Source; Agency for Natural Resources and Energy (2009) “Energy White Paper”

1.2 Current condition of existing databases of commercial buildings

Concerning stock of domestic residential buildings, there is “Housing and Land Survey（住宅・土地統計調査)” which is consecutive official statistical survey conducted on residential buildings. The survey has been useful to clarify the circumstances and trends of residential buildings of whole country. On the other hand, there is no general statistical survey and database covering all non-residential buildings in Japan. Ministry of economy, Trade and Industry (METI)/Agency for Natural Resources and Energy (ANRE) has conducted “Comprehensive Energy Statistics”（エネルギー消費統計）in order to clarify circumstances and trends of energy consumption by industrial and commercial sector. However, it is difficult to clarify total energy consumption of whole building because research unit of the survey is business institutions.

In addition, there are various private surveys, but the sample sizes of those surveys are small and the structures of each survey and database are different. According to a surveillance of domestic databases, sample size of databases targeting single city or prefecture is less than 100 in most of cases. Also sample size of databases targeting several cities or prefectures is less than 1000 in most of cases. Those sample sizes are not enough to clarify circumstances and trends of domestic commercial buildings. Adequate sample size for the database will be discussed in the next chapter. It is also a problem that most of surveys are single isolated and thus analysis of age variation or climate influence is impossible. As just described, general survey and database of domestic commercial buildings doesn’t exist and it is impossible to clarify actual circumstances and trends of energy consumption of entire domestic commercial buildings.

Table1.2-1 Sample size of existing literatures

Sample size	1_10	10_100	100_1000	1000_2000	total
Single city/prefecture	52	29	12	3	96
Several cities/prefectures	4	7	15	1	27

1.3 Demand for universal database

It was pointed out in the previous chapter that there is no general database which is necessary to promote energy conservation and reduction of greenhouse gas emission and it is the pressing issue to clarify the actual circumstances and trends of energy consumption of domestic buildings. Constructing expedient database will be useful for public and private sector and academic field. It will be applicable to estimate trends of energy consumption and possible amount of energy reduction for government. Also it will be useful for building owners to check the comparative energy performance of building and to plan improvement of energy performance of building. Furthermore, it will be valuable to construct accessible public database for academic fields.

Building equipments are divided into plumbing sanitary, air-conditioning system and electrical facility and these equipments are operated by a building unit not by business institution or tenant unit. Therefore the survey and analysis of commercial buildings should be examined by building base.

1.4 Utilization of DECC

DECC can be utilized for various purpose. Each 3 level database are useful to private sector, national or local government and academic sector. Utilization method of 3 level databases for 3 sectors are shown in table 1.4-1.

Table1.4-1 Utilization methods of DECC

	Basic database	Standard databse	Detail database
Private sector	energy performance indication	energy performance indication	performance verification
National Local gov.	development of action plan	formulate guideline of energy-saving measures	Environmental rabeling of equipment
Academy	development of future forecast method	effects verification of energy-saving measures	verification of simulation accuracy

Benchmarking of Building energy performance is the useful indicator to improve energy efficiency for building owner, tenant and also national or local governments. Energy Use Intensity (EUI) is representative indicator which is defined as yearly energy use per floor square meter. EUI can be used to compare with other similar buildings, government use it as reference point of environmental measures. Figure1.4-1 is an example of EUI histogram for office buildings in Kanto area obtained by the DECC 2008 survey. Buildings are divided into 3 groups; low-efficient (over upper quartile line), normal-efficient (between lower and upper quartile line), high-efficient (under lower quartile line). It is utilized for giving incentive to high-efficient buildings or penalty to low-efficient buildings. Figure1.4-2 shows another way of benchmarking. EUI which is weighted by floor space of buildings is used for categorization. In this method, upper quartile is a border of total energy consumption of top 25% and lower quartile is a border of total energy consumption of low 25%.

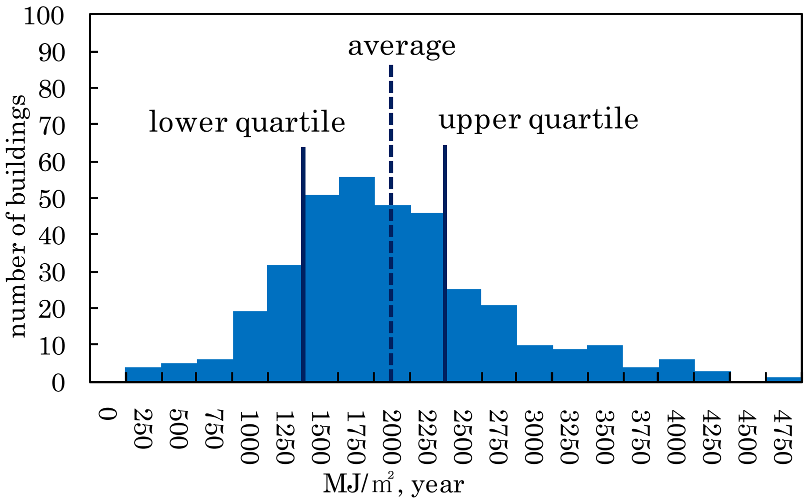


Figure1.4-1 EUI histogram for office buildings

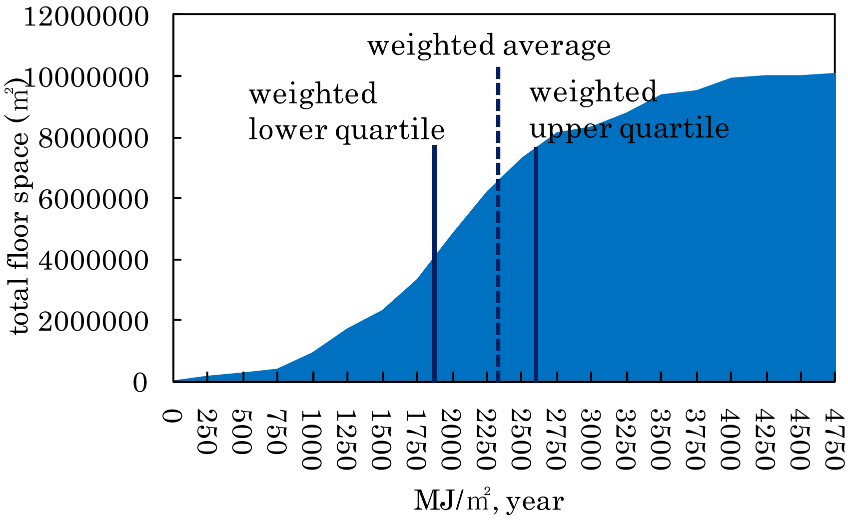


Figure1.4-2 EUI histogram for office buildings weighted by floor space

National and local governments become to be able to develop effective measurements by identifying energy-saving potential of buildings. Actually, several local governments in Japan have already conducted energy benchmarking measurements. In Europe Union Energy Performance of Buildings Directive (EPBD) provides that newly constructed non-dwelling buildings require Energy Performance Certificates (EPC) and also all existing buildings require EPC when it is sold or rent. Furthermore, EPC is used for commercial transaction. It is expected that renovation of buildings will be encouraged by introducing EPC to price formation of real-estate.

1.5 Study purpose

The purpose of this paper is to clarify the actual situation of energy use in commercial buildings and to discuss an appropriate analysis method for DECC utilization from the results of 2007 and 2008 survey for DECC.

2. Overview of DECC

2.1 Basic structure of DECC

DECC committee was established in "Institute for Building Environment and Energy Conservation" (administered by the "Ministry of Land, Infrastructure, Transport and Tourism") in 2007 and has conducted the survey and database construction. Outline of DECC is summarized in the following. Generally, necessary data for database such as building specification, building usage and energy consumption is managed by building owner or building management company and content of the data are very varied from buildings. Therefore the field items of each level database should be different due to a variety of circumstances. DECC is consists of 3 levels.

Basic Database (level 1)

Content： Basic information of building + annual energy consumption

Purpose：

1) Clarify the entire picture of energy consumption and carbon dioxide emission
2) Develop the reference value of buildings

Standard Database (level 2)

Content： Level 1 + information of building equipments + monthly energy consumption

Purpose：

1) Clarify factors of energy consumption
2) Clarify effectiveness of energy saving measures

Detail Database (level 3)

Content： Specification of equipment + hourly energy consumption

Purpose：

1) Clarify hourly energy consumption
2) Detailed analysis of energy consumption
3) Clarify characteristic and performance of equipments

2.2 Required data items for energy consumption structural analysis

Collected data items are divided into two main category; Building attribute and Energy use. Basic information of Building attribute shown in Table2.2-1 should be collected in all 3 level database. Data of Implementation status of Energy saving measures and existence of energy saving equipments are collected in level 2 database which is shown in Table2.2-2. There are two sides of energy use; Supply side (Table2.2-3) and Demand side (Table2.2-4). Generally, Building owner is easily able to know the building energy consumption receiving acknowledgment of energy consumption by electric power company, gas company, oil company, DHC company and water company. Annual energy consumption data were collected in level 1 survey, and monthly energy consumption was collected in level 2 survey. On the other hand, energy use of demand side is rarely measured and unknown. Monthly end-use energy consumptions are collected in level 2 survey and more detailed end-use consumption and energy use of each equipment are collected using BEMS(Building Energy Measurement System) or other actual measurements.

Table2.2-1 Building attribute and usage information

Building information	User information	Equipment information
floor space	operation hour	heat source sytem
parking space	preset temperature	heat source
floor number	cooling period	power generation system
age	heating period	
location	vacancy rate	
building use ratio	head-count	
ownership pattern		
electricity contract		
renovation date		

Table2.2-2 Energy saving measures and equipments

Energy saving measure	Energy saving equipment
demand monitoring system	preset T. adjustment
cogeneration system	air-con. period adjustment
automatic on-off light	extinction of unnecessary light
highly-efficient light	power saving of unused O.A. equipment
thermal storage tank	restriction of using ELV/ESC
outdoor air cooling	adoption of thermal insulant or multiple glass
heat recovery HP	adoption of renewable energy
total heat exchanger	
CO2 conrol ventilation	
Variable Air Volume system	
Variable Water Volume system	
water-saving equipment	
rainwater utilization	
drainage utilization	

Table2.2-3 Supply side

Supply side	
electricity	day electricity
	night electricity
	solar/wind
gas	not CGS
	CGS
oil	not CGS
	CGS
cold energy	cold energy
heat energy	heat energy
steam	steam
level 1	level2

Table2.2-4 Demand side

Demand side				
air-conditioning /ventilation	air-conditioning	heat source system	cold	refrigerator
				auxiliary
			heat	boiler/heat pump
				auxiliary
		water delivery	primary pump	primary pump
			secondary pump	secondary pump
	ventilation	air-conditioning fan	air-conditioning	air-conditioning system
			air-conditioning	air-conditioning fan
		ventilation fan	ventilation fan	ventilation fan
lighting/ socket	lighting/ socket	lighting	indoor lighting	indoor lighting
			outdoor lighting	outdoor lighting
		socket	socket	socket
other	hot-water	hot-water	hot-water supply	hot-water supply
	other	water supply and drainage	water supply	water supply pump
				water cleaner
			water drainage	drainage pump
				drainage system
		ELV/ESC	ELV/ESC	ELV
				ESC
		tenant	tenant	tenant refrigerator
				tenant other
		other	kitchen	kitchen
			other	other
level 2		level3		

2.3 Building types

Buildings are classified according to type of activity, business or function carried on each building. Buildings are divided into 23 types which are shown in table 2.3-1. Buildings used for several activities are assigned to the activity occupying most floor space when it is more than 60%. In the case any activities occupying more than 60 % of floor space, such buildings are assigned to "complex facility".

Table2.3-1 Building types and definition

Building types	ID	Elementary school	12
Office	01	High school	13
Computer / Information center	02	University, College	14
Public	03	Research institution	15
Hotel	08	Theater, Hall	16
Department store	04	Exhibition hall	17
Convenience store	06	Sports gym	18
Food service	07	Complex	20
Resident	05	Home electronics retail	21
Hospital	09	Suburb large retail	22
Welfare institution	10	Other retail	23
Kindergarten	11	Other	99

2.4 Sample size determination

Interval estimation method was used to calculate the sample size design of Basic Database as following. Basic Database is utilized for benchmark method which is explained in chapter1.4. Therefore, we need to calculate statistically confidential value of average EUI for each building type and area.

Population average and population variation are unknown and sample average and sample variation are obtained by primary survey.

Sample mean is normally-distributed [N(μ, σ²/n)]

Standardized $u = \dfrac{\bar{x} - \mu}{\sqrt{\sigma^2 / n}}$ is standard normally-distributed.

$T = \dfrac{\bar{x} - \mu}{\sqrt{V / n}}$ in which unbiased estimator(V) assigned to σ^2 possesses t distribution

with n-1 degrees of freedom.

Two sided confidential interval is 95% and α = 0. 05, {t(n-1, α)} = 1. 960.

$$
\begin{aligned}
0.95 &= \Pr\{-t(n-1,\alpha) \le T \le t(n-1,\alpha)\} \\
&= \Pr\{-t(n-1,\alpha) \le \frac{\bar{x} - \mu}{\sqrt{V / n}} \le t(n-1,\alpha)\} \\
&= \Pr\{\bar{x} - t(n-1,\alpha)\sqrt{V / n} \le \mu \le \bar{x} + t(n-1,\alpha)\sqrt{V / n}\}
\end{aligned}
$$

Pr : Probability, t(freedom degree, significance level): t-distribution

Acceptable range is $e(\%) = \dfrac{t(n-1,\alpha)}{\bar{x}}\sqrt{\dfrac{V}{n}}$ and transformed to $n \ge \dfrac{t(n-1,\alpha) \cdot V}{\bar{x}^2 \cdot e^2}$

On the first survey in 2007, the sample average and variation of office building in Tokyo obtained by the existing survey was used as a reference data to calculate sample size. From following survey in 2008 and 2009, each average and variation value of each building type and area which obtained by previous year survey was used as the reference value. Also the distribution of buildings was considered to determine setting of numerical targets for the survey. However, the stock of domestic commercial buildings is not confirmed. Therefore, we consulted "Building Stock Estimation" and allocate the numerical targets of 8 zones.

Table2.4-1 Stock estimation of commercial buildings

Building type	Office	Store	Storehouse
Number	1,333,356	859,220	2,821,223
Floor space	494,089,404	325,405,758	516,949,304
Building type	Education	Hospital	Other
Number	310,107	310,908	4,440,850
Floor space	309,313,256	74,829,281	565,181,960

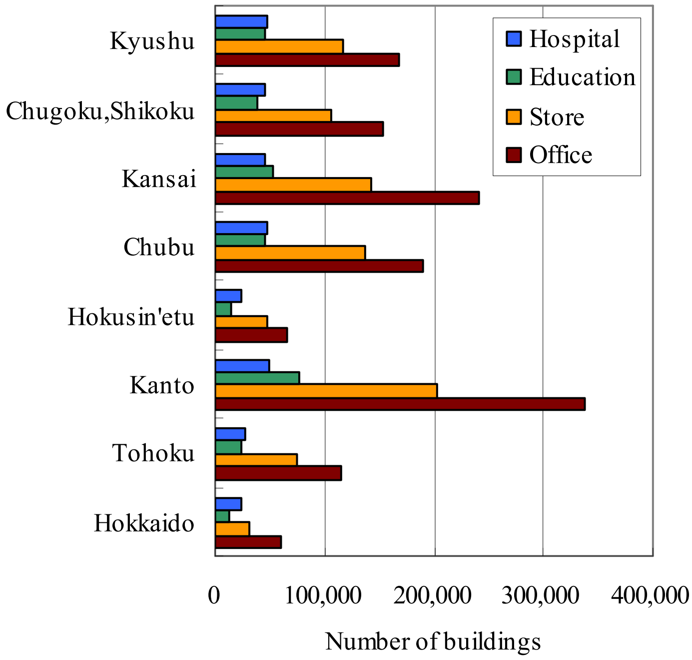


Figure2.4-1 Number of buildings

Source; Statistical building stock Council (2002) “Building Stock Estimation Report”

2.5 Method of survey for DECC

Different survey methods were conducted for each level database. Mail survey was conducted as level 1 survey because the number of level 1 survey is numerous and only basic data is required. Questionnaire is sent to building owner and they can response using reply envelope or web questionnaire. Level 2 survey includes more technical questions therefore hearing survey on telephone was conducted after sending questionnaire on first year 2007 survey. From second year 2008 survey, level 1 and level 2 questionnaires were united and only mail survey was conducted.

Table2.5-1 Level 1 survey steps

List up addresses
⇩
Send questionnaires
⇩
Collect questionnaires
⇩
Data entry
⇩
Anonymizing
⇩
Registration to Database
⇩
Outlier detection
⇩
Analysis
⇩
Report

Table2.5-2 Level 2 survey steps

List up addresses from level 1 response
⇩
Send questionnaires
⇩
Hearing survey
⇩
Collect questionnaire
⇩
Data entry
⇩
Anonymizing
⇩
Registration to Database
⇩
Analysis
⇩
Report

Number of respondents to the survey for each building type and area is determined by considering sample size calculation. Respondent selection and survey job such as distribution and collection of questionnaire is conducted by Sub Working Groups (SWG). SWGs are consists of following 8 areas; Hokkaido, Tohoku, Hokushin'etu, Kanto, Chubu, Kansai, Shikoku-Chugoku, Kyushu and members of each SWG consist of 5 to 10 universities or private think tanks.

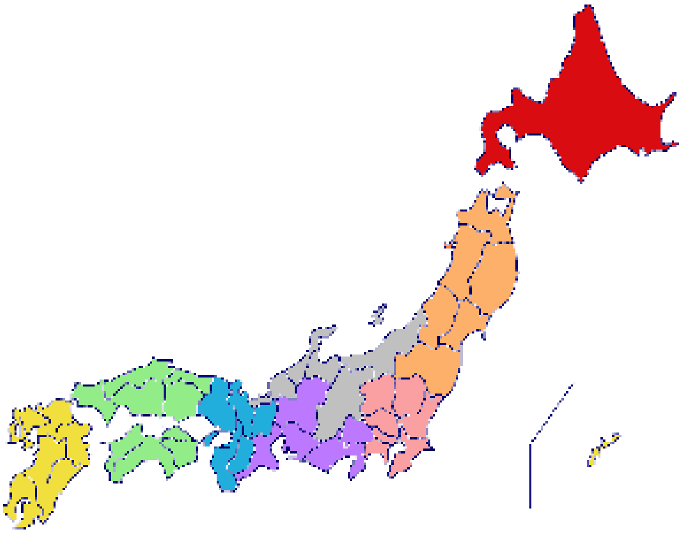


Figure2.5-1 Area division

2.6 Energy conversion factor

We used the primary energy conversion factors in order to unify quantity of energy; electricity, gas, oil, etc. Primary energy conversion factors are shown in Table2.6-1. The primary energy conversion factors of city gases are varied with its composition which is different between each supplier, hence proper factor was assigned to each area.

Table2.6-1 Primary energy conversion factors

Energy types	Factors
Day electricity	9. 97MJ/kWh
Night electricity	9. 28MJ/kWh
City gas	Various
LPG	100. 5MJ/m^3
A Heavy oil	39. 1GJ/kL
B,C Heavy oil	41. 7GJ/kL
Paraffin oil	36. 7GJ/kL
Light oil	38. 2GJ/kL
DHC	1.36MJ/MJ

2.7 Outlier detection method

There are some outlier values of EUI in the database. When statistical value such as mean value and standard deviation are calculated by original data, outliers are excluded in advance by the Smirnov-Grubbs outlier test at 5% significance level. All sets of each building types and areas were tested.

The Smirnov-Grubbs outlier test

Pick up n samples from normal-distributed population and form following hypotheses.

Null hypothesis; Max value is not error

Alternative hypothesis; Max value is error

Sample data are $X_1, X_2,,, X_n$ and sample average is $\overline{X}$ and variance is V.

Test statistic is $T_{\max} = \frac{|X_{\max} - \overline{X}|}{\sqrt{V}}$

If alternative hypothesis is adopted and max value is excluded as error, calculate 't' of n-1 data again. The test is repeated till null hypothesis is adopted.

3. Results of survey

3.1 Basic and standard Database

3.1.1 Response rate and missing data

In this chapter, results of response rate and missing data items of the survey are shown. Table3.1.1-1 summarizes numbers of mailed questionnaires of 2008 survey, and Table3.1.1-2 summarizes numbers of responses. Response rates of mail survey are greatly different from each building type. The response rate of Hotel is especially low in both years. On the contrary, response rate of Public and Educational buildings is higher than other types.

Table3.1-1 Number of mailed questionnaires of 2007 survey

Sending	Hokkaido	Tohoku	Kanto	Chubu	Kansai	ugoku,Shik	Kyushu	Total
Office	94	663	1001	0	355	595	637	3345
Computer / information	0	0	107	0	19	140	7	273
Public	36	242	753	0	257	400	234	1922
Mercantile	57	432	1693	0	1240	780	2191	6393
Hotel	127	385	1147	235	613	410	407	3324
Hospital	559	1082	1656	785	888	715	512	6197
Education	590	966	660	0	1050	490	468	4224
Culture	762	152	1227	0	84	260	385	2870
Other	14	83	0	0	95	210	93	495
Total	2239	4005	8244	1020	4601	4000	4934	29043

Table3.1-2 Response number of 2007 survey

Response	Hokkaido	Tohoku	Kanto	Chubu	Kansai	ugoku,Shik	Kyushu	Total
Office	48	138	138	16	189	149	138	816
Computer / information	0	0	5	0	15	0	0	20
Public	46	141	316	67	144	203	91	1008
Mercantile	46	150	190	256	143	90	192	1067
Hotel	20	85	121	58	82	49	85	500
Hospital	105	168	235	170	151	156	86	1071
Education	622	751	772	467	183	145	142	3082
Culture	150	48	192	31	127	96	84	728
Other	0	0	242	71	54	75	9	451
Total	1037	1481	2211	1136	1088	963	827	8743

Table3.1-3 Response rate of 2007 survey

Reponse rate	Hokkaido	Tohoku	Kanto	Chubu	Kansai	ugoku,Shik	Kyushu	Total
Office	51%	21%	14%		53%	25%	22%	24%
Computer / information			5%		79%			7%
Public	_	58%	42%		56%	51%	39%	52%
Mercantile	81%	35%	11%		12%	12%	9%	17%
Hotel	16%	22%	11%	25%	13%	12%	21%	15%
Hospital	19%	16%	14%	22%	17%	22%	17%	17%
Education	_	78%	_		17%	30%	30%	73%
Culture	20%	32%	16%		_	37%	22%	25%
Other					57%	36%	10%	91%
Total	46%	37%	27%	111%	24%	24%	17%	30%

Table3.1-4 Number of mailed questionnaires of 2008 survey

Sending	Hokkaido	Tohoku	Kanto	Chubu	Kansai	ugoku,Shik	Kyushu	Total
Office	71	1095	1843	0	828	1089	841	5767
Computer / information	0	0	120	0	17	0	1	138
Public	20	236	690	24	210	300	353	1833
Mercantile	40	2800	2874	187	2102	1992	1454	11449
Hotel	127	589	2262	243	617	601	409	4848
Hospital	596	722	1625	781	824	270	695	5513
Education	655	1196	523	1064	1326	1417	856	7037
Culture	797	296	1363	619	349	304	568	4296
Other	0	555	3470	464	608	898	263	6258
Total	2306	7489	14770	3382	6881	6871	5440	47139

Table3.1-5 Response number of 2008 survey

Response	Hokkaido	Tohoku	Kanto	Chubu	Kansai	ugoku,Shik	Kyushu	Total
Office	34	225	387	81	181	169	184	1261
Computer / information	0	0	12	1	17	0	5	35
Public	31	146	444	41	140	143	139	1084
Mercantile	122	1222	2030	622	718	268	486	5468
Hotel	13	85	190	50	72	64	63	537
Hospital	190	243	424	263	227	180	139	1666
Education	598	1407	1194	615	319	318	350	4801
Culture	186	113	274	206	211	122	188	1300
Other	0	0	88	15	52	69	72	296
Total	1174	3441	5043	1894	1937	1333	1626	16448

Table3.1-6 Response rate of 2008 survey

Reponse rate	Hokkaido	Tohoku	Kanto	Chubu	Kansai	ugoku,Shik	Kyushu	Total
Office	48%	21%	21%		22%	16%	22%	22%
Computer / information			10%		100%		_	25%
Public	_	62%	64%	_	67%	48%	39%	59%
Mercantile	_	44%	71%	_	34%	13%	33%	48%
Hotel	10%	14%	8%	21%	12%	11%	15%	11%
Hospital	32%	34%	26%	34%	28%	67%	20%	30%
Education	91%	_	_	58%	24%	22%	41%	68%
Culture	23%	38%	20%	33%	60%	40%	33%	30%
Other			3%	3%	9%	8%	27%	5%
Total	51%	46%	34%	56%	28%	19%	30%	35%

There is difference of response rate between building scale. Table3.1.1-7 shows the result of department store in Kanto area of 2007 level 1 survey. Response rate of smaller buildings is lower than large buildings. It is likely that it is difficult for small buildings to complete the questionnaire because there is few person who expertly manages energy and building facilities and completing of questionnaire is time-consuming task for small stores.

Table3.1-7 Response rate and floor space of department store [D04]

Floor space	Mail circulation	Response number	Response rate
1_2000m^2	152	8	5%
2000_30000 m^2	829	115	14%
Over 30000 m^2	181	61	34%
Unknown	272	17	6%
Total	1434	201	14%

Secondary problem is missing data in the questionnaire and data existence. There are several possible causes of data missing. 1) Datum is not measured or saved in a building. 2) Question requires technical knowledge to complete. 3) datum is unable to be released (confidential data). 4) Question is incomprehensible. Table3.1.1-8 shows missing rate of some data items in department store and office. Some data items, for example building type ratio and data coverage are indispensable for the statistical analysis. Data coverage is a question about coverage of energy consumption data which is obtained by response.

The question includes 3 selections; Energy consumption data is obtained by 1) Single building, 2) all buildings in the area, 3) part of a building.

Table3.1-8 Missing data of department store [D04] and office [D01]

Data item	[D04]	[D01]
Building type ratio	17%	23%
Data coverage	40%	54%
Parking floor space	27%	18%
Cooling period	22%	17%
Heating period	33%	17%
Electricity contract	11%	9%

We also surveyed existence of detail data such as monthly energy end-use in 2007 survey and existence of BEMS in 2008 survey. The results appeared in Figure3.1.1-1 and Figure3.1.1-2. More than half of University (D14), Office (D01), Theater/Hall (D16) and Sports gym (F18) possess level 2 data while other building types possess at low rates. Also, BEMS is installed to relatively many Office (D01), University (D14), Research (D15) and Theater/Hall (D16), but data existence is at very low rate in whole.

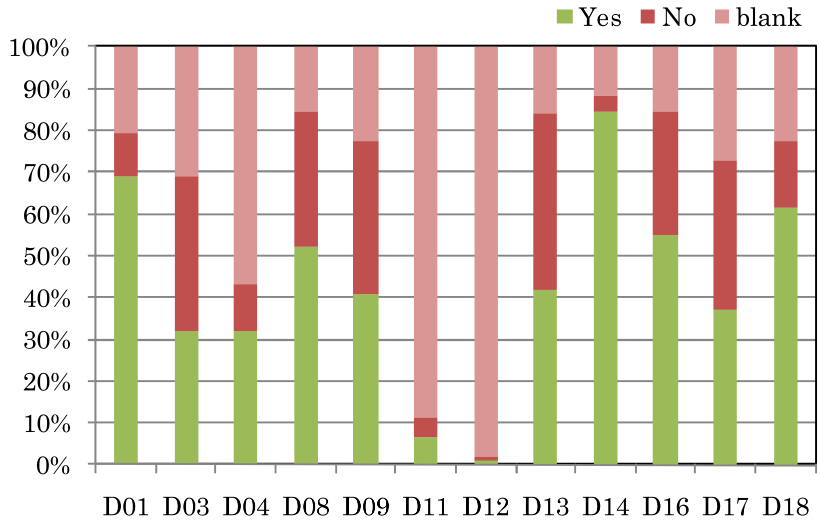


Figure3.1-1 Existence of level 2 data

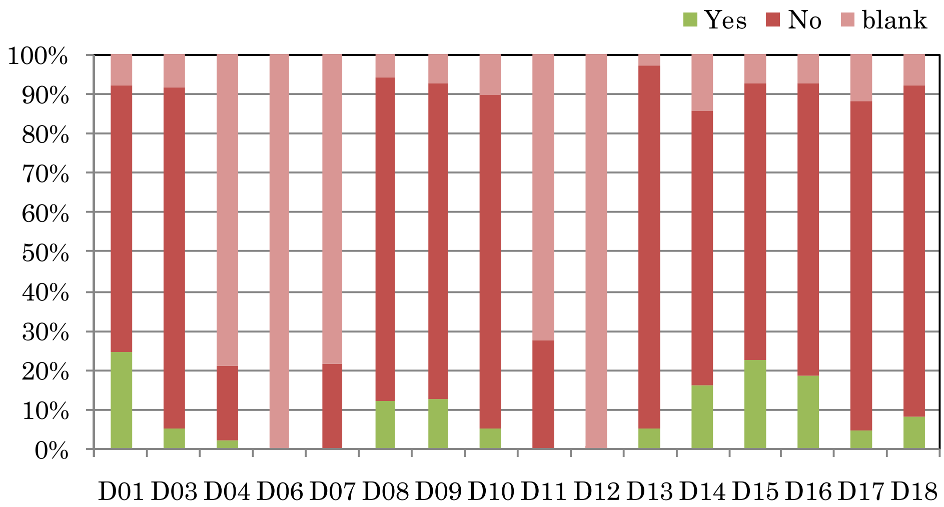


Figure3.1-2 Existence of BEMS

3.1.2 Calculation of Sample size using results of the survey

Required sample size is calculated using results of the survey. Number of required sample which is calculated by using 2006 and 2007 data are shown in Table3.1.2-1 and Table3.1.2-2. Acceptable range e(%) is determined as 10%. Also, Required number which is calculated using combined data of 2006 and 2007 is shown in Table3.1.2-3. Colored cells indicate deficiency of collected data compared to required sample size. Although, The number of collected sample in Kanto area reach to the number of required samples in most of building types, there is shortage of the collected sample in other areas. In addition, building types which including large variance such as Sports gym, Kindergarten require large sample size and the number of collected sample is not enough yet. However, it is assumed that the classification of building types and areas used here is not best suited for actual condition of buildings. Proper classification for EUI is discussed in next chapter.

Table3.1.2-1 Sample size calculated by 2006 data

	Hokkaido	Tohoku	Kanto	Chubu	Kansai	Chugoku,Shikoku	Kyushu
Office	40	103	57	58	62	66	74
Public	136	37	52	-	61	53	100
Department store	134	84	85	54	89	57	84
Other retail	-	-	-	53	74	37	125
Convenience store	-	-	-	-	-	-	-
Food service	-	-	-	-	-	-	-
Hotel	79	104	56	51	58	40	65
Hospital	46	57	69	66	60	37	86
Welfare institution	-	49	-	23	88	-	141
Kindergarten	-	-	137	67	152	179	-
Elementary school	59	52	78	31	48	79	-
High school	66	54	117	30	86	43	62
University, College	65	-	33	-	76	133	209
Research institution	-	-	-	-	-	-	-
Theater, Hall	135	-	144	-	148	50	-
Exhibition hall	130	127	64	-	50	107	57
Sports gym	118	312	114	-	224	-	244
Complex	-	-	77	-	-	-	-

Table3.1.2-2 Sample size calculated by 2007 data

	Hokkaido	Tohoku	Kanto	Chubu	Kansai	Chugoku,Shikoku	Kyushu
Office	39	66	51	98	50	54	72
Public	60	43	39	126	54	56	1216
Department store	408	57	155	67	64	56	73
Convenience store	-	10	18	5	32	26	-
Food service	-	178	129	99	86	53	-
Hotel	33	50	56	39	53	69	33
Hospital	44	37	46	43	42	36	50
Welfare institution	-	70	52	130	60	91	46
Kindergarten	-	89	224	38	33	99	-
Elementary school	48	109	42	38	37	93	-
High school	39	38	75	64	80	60	83
University, College	90	144	59	105	59	77	169
Theater, Hall	150	49	117	108	82	104	81
Exhibition hall	117	109	53	161	142	62	183
Sports gym	158	317	93	270	155	171	220
Complex	-	-	65	169	120	-	139
Home electronics	145	-	-	-	620	71	-
Suburb large retail	-	-	105	-	56	14	91
General retail	-	-	109	-	-	-	-

Table3.1.2-3 Sample size calculated by 2006 and 2007 data

	Hokkaido	Tohoku	Kanto	Chubu	Kansai	Chugoku,Shikoku	Kyushu
Office	38	81	54	88	56	61	72
Computer information center	-	-	-	-	158	-	-
Public	108	40	46	131	57	54	820
Department store	411	69	136	60	74	56	80
Other retail	-	146	-	54	69	37	125
Convenience store	-	10	18	5	32	26	-
Food service	-	-	129	99	89	53	-
Hotel	56	71	56	45	55	58	52
Hospital	45	48	57	53	50	37	66
Welfare institution	-	60	52	104	72	97	78
Kindergarten	-	89	177	55	284	100	-
Elementary school	55	87	58	35	38	84	146
High school	54	46	100	60	81	58	77
University, College	67	144	48	105	65	111	189
Research institution	-	-	101	49	192	126	-
Theater, Hall	130	50	130	156	112	79	74
Exhibition hall	122	123	61	185	95	92	128
Sports gym	120	256	98	254	224	607	238
Complex	-	-	70	254	83	-	137
Home electronics	145	-	-	-	544	71	-
Suburb large retail	-	-	105	-	56	14	91
General retail	-	-	109	-	-	-	-

Table3.1.2-4 Required sample size

	Hokkaido	Tohoku	Kanto	Chubu	Kansai	Chugoku,Shikoku	Kyushu
Office	39	231	517	3	290	223	196
Computer information center	-	-	-	-	(128)	-	-
Public	(36)	227	504	(88)	207	276	(611)
Department store	(335)	257	362	227	140	90	68
Other retail	-	(95)	-	59	(4)	(19)	(16)
Convenience store	-	796	1038	238	213	(14)	-
Food service	-	-	(101)	(53)	107	(8)	-
Hotel	(25)	55	251	55	97	47	80
Hospital	276	244	402	266	232	202	97
Welfare institution	-	82	101	(50)	10	(17)	(54)
Kindergarten	-	(52)	(38)	(22)	(230)	(49)	-
Elementary school	529	936	1214	723	67	(12)	(136)
High school	291	450	19	40	79	100	216
University, College	(22)	(115)	27	(70)	58	12	(66)
Research institution	-	-	9	(39)	(176)	(85)	-
Theater, Hall	(90)	(6)	70	(66)	(5)	(4)	(36)
Exhibition hall	110	(30)	186	(132)	10	(19)	6
Sports gym	(89)	(237)	(42)	(224)	(136)	(579)	(193)
Complex	-	-	(4)	(203)	(62)	-	(120)
Home electronics	(101)	-	-	-	(529)	(18)	-
Suburb large retail	-	-	(70)	-	(39)	44	(72)
General retail	-	-	(25)	-	-	-	-

Notes; Numbers in black indicate excess number compared to the sample size. Numbers in red indicate deficient number compared to the sample size.

3.1.3 EUI for building types and areas

Average EUI of 20 building types and 8 area obtained by the 2006 and 2007 samples are shown in Table3.1.3-1 and Table3.1.3-2. Also, EUI which is calculated using combined data of 2006 and 2007 is shown in Table3.1.3-3. EUI can be used as benchmark for energy performance of building and it is used for the reference point of environmental measures. Therefore EUI should be calculated in appropriate classification. From the result, reconsideration of classification by use and area and also different framework of classification is required.

Table3.1.3-1 Average EUI (2006)

	A	B	D	E	F	G	H	
[MJ/m^2, year]	Hokkaido	Tohoku	Kanto	Chubu	Kansai	Shikoku	Kyushu	Average
Office	1775	1431	2296	1888	1885	1572	1628	1825
Computer information center	-	-	21857	-	8889	-	-	11177
Public	1722	1119	1136	762	1079	1009	1088	1118
Department store	4250	5186	4685	3396	4584	4033	4278	4443
Other retail	-	-	-	2511	2846	2619	2934	2729
Convenience store	-	-	-	-	-	-	-	-
Food service	-	-	-	-	5660	-	6756	6208
Hotel	2748	2457	2885	2541	2828	2448	2594	2685
Hospital	2336	2448	2590	2668	2591	2193	2142	2448
Welfare institution	-	2383	-	2022	1392	1813	1236	2007
Kindergarten	-	-	961	298	622	298	-	748
Elementary school	594	344	337	277	245	357	372	369
High school	539	409	434	291	383	270	316	417
University, College	1178	-	1376	-	836	883	991	992
Research institution	-	-	-	-	2666	-	2949	2713
Theater, Hall	1005	1760	1469	3405	1213	1075	1016	1325
Exhibition hall	1047	1535	1190	1724	1302	1340	1125	1206
Sports gym	1306	2316	1733	2565	1697	3003	1719	1776
Complex	-	-	1553	3833	3138	988	2732	2026
Other	-	-	1214	-	6134	2893	5281	2467
Average	1280	1427	1782	1684	2174	1721	2025	1721

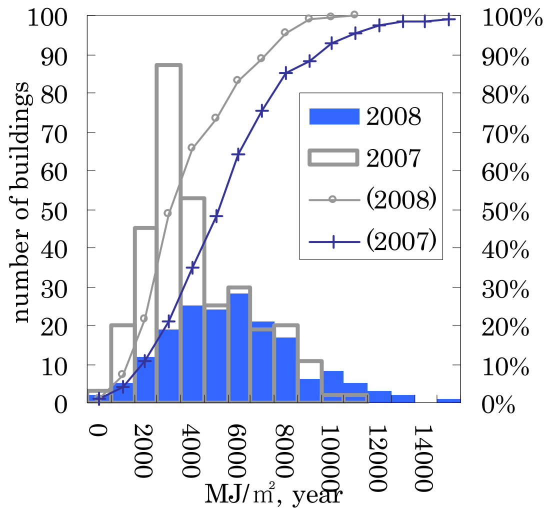
Table3.1.3-2 Average EUI (2007)

[MJ/m², year]	Hokkaido	Tohoku	Kanto	Chubu	Kansai	Shikoku	Kyushu	Average
Office	1795	1338	2121	1729	1898	1402	1633	1762
Computer information center	-	-	-	1748	8980	-	2967	8244
Public	1518	1177	1224	1165	1093	989	1348	1183
Department store	8520	5003	6586	3293	4901	3801	3913	5011
Convenience store	-	16492	13804	13231	11736	10460	-	14431
Food service	-	12474	15589	14454	16300	8267	1452	14663
Hotel	2724	2550	2820	2491	2801	2758	2661	2724
Hospital	2199	2296	2745	2489	2765	2341	2331	2485
Welfare institution	-	2070	1828	1294	2044	1313	1652	1755
Kindergarten	-	480	861	247	201	312	745	515
Elementary school	682	400	371	281	250	313	430	397
High school	467	390	472	330	363	311	307	373
University, College	1018	1312	1200	821	863	746	978	959
Research institution	-	816	3248	3050	3054	1640	2034	2820
Theater, Hall	994	1292	1585	715	1033	958	1128	1107
Exhibition hall	1035	1169	1422	744	1075	1631	945	1120
Sports gym	1411	2728	1853	1728	3772	1108	1135	2209
Complex	-	-	1566	1771	2803	1080	2579	1987
Home electronics	3267	-	-	3758	2634	2973	-	3058
Suburb large retail	-	1764	2550	3031	1434	1542	3504	2116
General retail	-	-	3229	-	-	1830	-	3213
Other	2196	-	1348	1738	2003	2372	371	2268
Average	1452	6218	5216	3519	4994	1877	1359	4309

Table3.1.3-3 Average EUI (2006,2007)

[MJ/m², year]	Hokkaido	Tohoku	Kanto	Chubu	Kansai	Chugoku,Shikoku	Kyushu	Average
Office	1783	1375	2187	1757	1892	1484	1630	1790
Computer information center	-	-	21857	1748	8937	-	2967	9669
Public	1643	1148	1177	1100	1086	1001	1228	1149
Department store	6160	5087	5372	3344	4752	3907	4174	5011
Other retail	-	6245	-	2522	2940	2619	2934	4889
Convenience store	-	16492	13804	13231	11736	10460	-	14431
Food service	-	12474	15589	14454	16191	8267	4104	14663
Hotel	2738	2510	2847	2521	2816	2631	2619	2724
Hospital	2261	2371	2666	2562	2688	2247	2239	2444
Welfare institution	-	2203	1828	1456	1877	1332	1444	1755
Kindergarten	-	480	906	275	310	310	745	515
Elementary school	636	372	355	279	249	330	395	397
High school	496	400	446	324	371	302	310	373
University, College	1132	1312	1261	821	851	818	986	959
Research institution	-	816	3248	3050	2933	1640	2339	2820
Theater, Hall	999	1314	1518	745	1104	1002	1107	1107
Exhibition hall	1041	1311	1294	818	1172	1412	1011	1120
Sports gym	1350	2511	1786	1756	2946	1514	1356	2209
Complex	-	-	1557	2095	2930	1007	2624	2005
Home electronics	3267	-	-	3758	2702	2973	-	3058
Suburb large retail	-	1764	2550	3031	1434	1542	3504	2116
General retail	-	-	3229	-	-	1830	-	3213
Other	2196	-	1276	1738	3774	2669	756	2240
Average	1368	4493	3896	2871	3953	1810	1679	3284

There are differences of EUI between 2007 and 2008 surveys. It is considered that large difference is caused by collecting different characteristic sample in each year. Floor space size is one of the factor of EUI for some building types. For example, average EUI of department store 2007 is much higher than 2006 because 2006 data includes much lower EUI buildings. EUI of department store are varied with its floor space size. We see from figure3.1.3-2 that EUI of department store are obviously lower in larger buildings. Office building shows opposite trend that EUI of larger buildings are slightly higher than smaller buildings (Figure3.1.3-4). It is considered that these building types should be divided by the size of floor space.



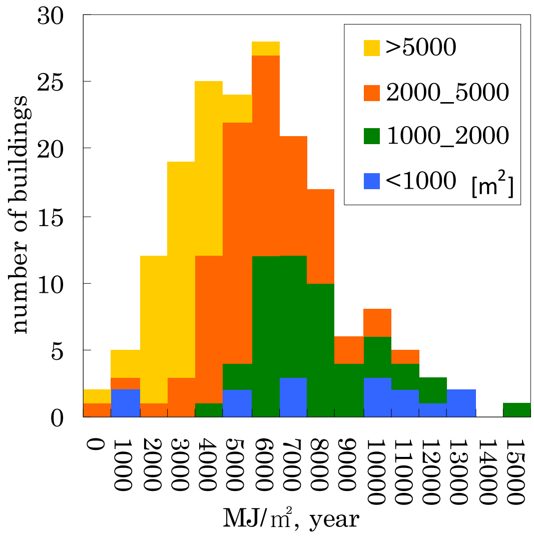
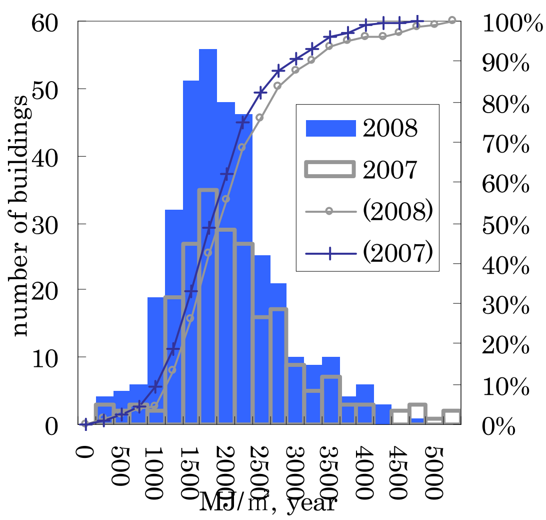


Figure3.1.3-1 EUI for department store in Kanto area [D04] (left)

Figure3.1.3-2 EUI for department store divided by building size in Kanto area [D04] (right)



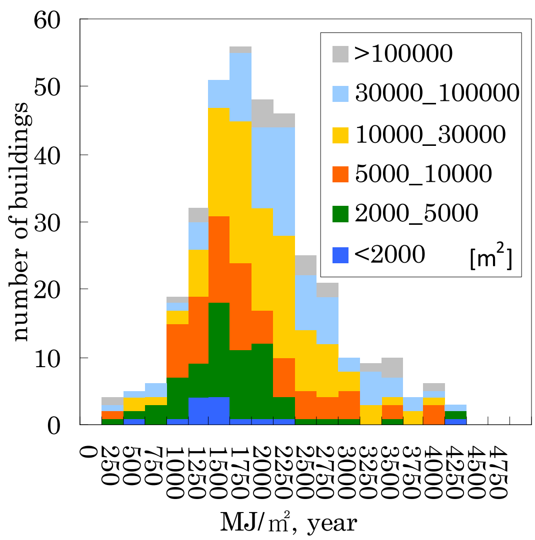
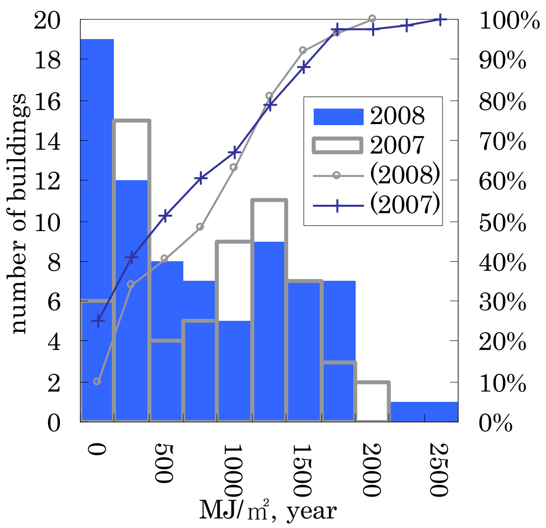


Figure3.1.3-3 EUI for office in Kanto area [D01] (left)

Figure3.1.3-4 EUI for office divided by building size in Kanto area [D01] (right)

As Figure3.1.3-5 shows, EUI for Kindergarten in Kanto area (D11) have wide variety and it is assumed that samples include different character groups. 76 data of kindergarten in Kanto area are arranged in ascending order and divided into 8 groups and average monthly EUI of each group is shown in Figure3.1.3-6. It shows that fluctuations of EUI for groups shown in blue lines; 0_10, 11_20, 21_30 are different from groups shown in orange lines; 51_60, 61_70, 71_76. There is no cooling load for blue line groups and EUI are much smaller than orange line groups. It is assumed that Kindergarten [D11] includes differently-used groups of buildings. It is considered that buildings classification should be divided depend on actual energy use pattern



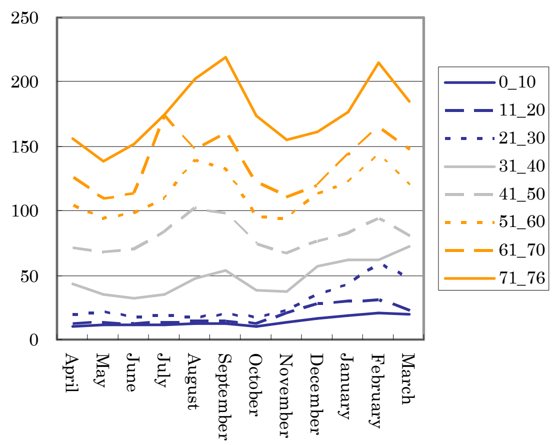
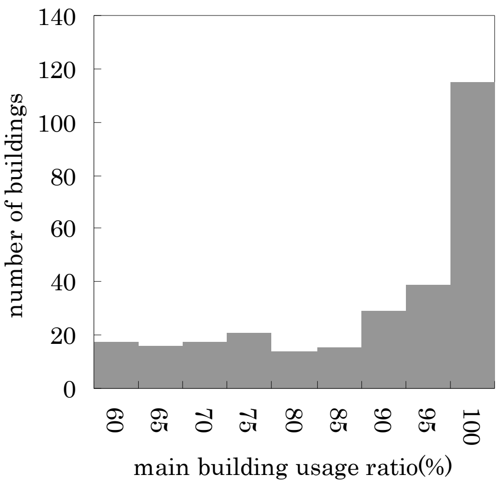
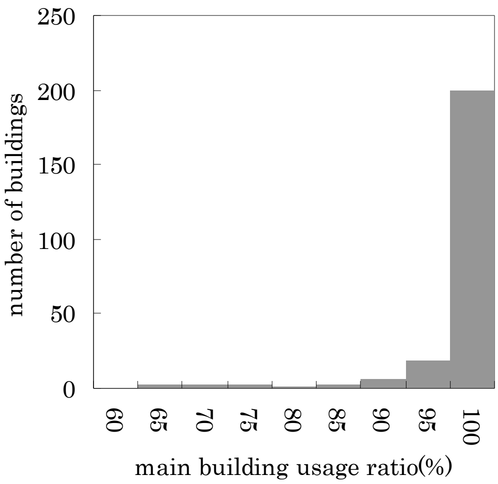


Figure3.1.3-5 EUI for elementary school in Kanto area [D11] (left)
Figure3.1.3-6 Monthly EUI for elementary school in Kanto area [D11] (right)

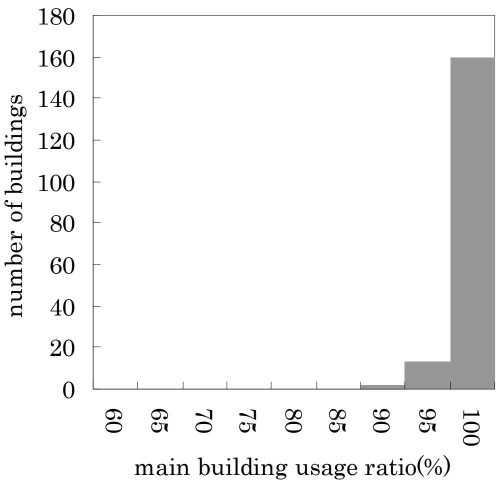
Building use ratio is also the factor of EUI variety. In this study, we classify buildings according to the rule which is shown in chapter 2.3. Following figure3.1.3-7 is histogram of main building usage ration in each building type sample. Main building usage ratio of Office [D01], Theater/Hall [D16] and Sports gym [D18] is quite variable. From the survey results, most office buildings include Computer/Information center, food service, convenience store, residence, etc. Average EUI of 100% office use buildings is 1887(MJ/m^2, year), as against 2280(MJ/m^2, year) for office which includes other building usages.



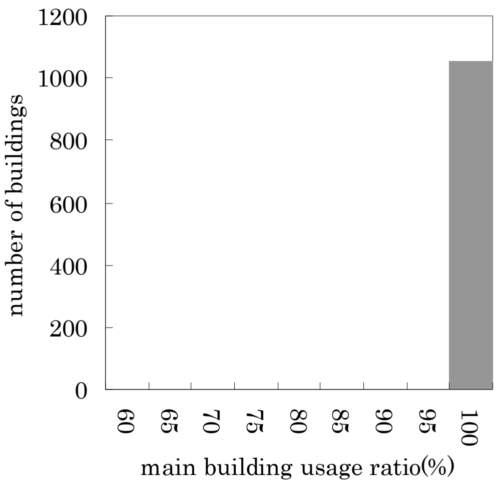
[D01]



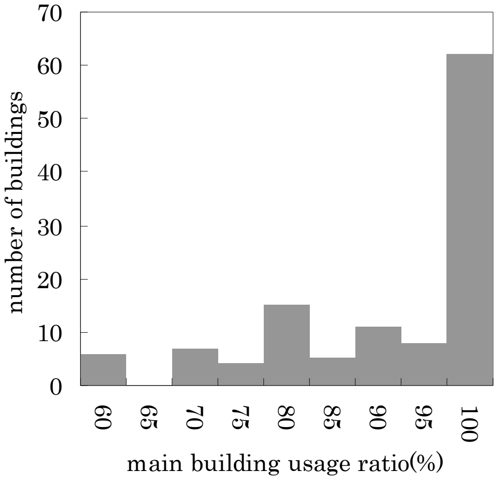
[D03]



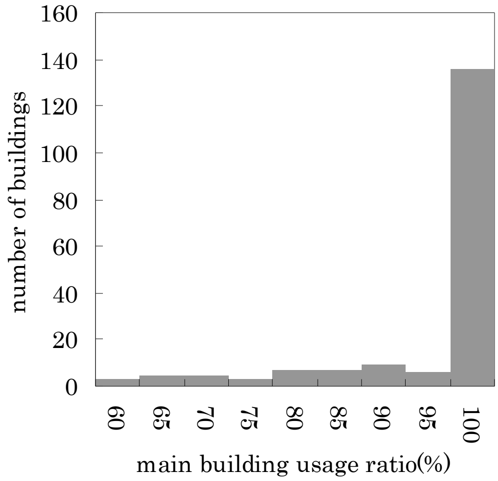
[D04]



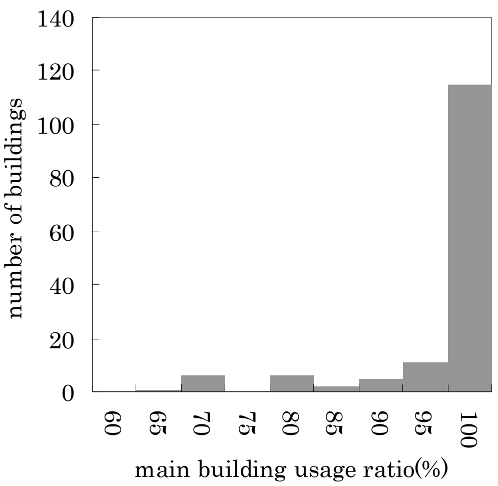
[D06]



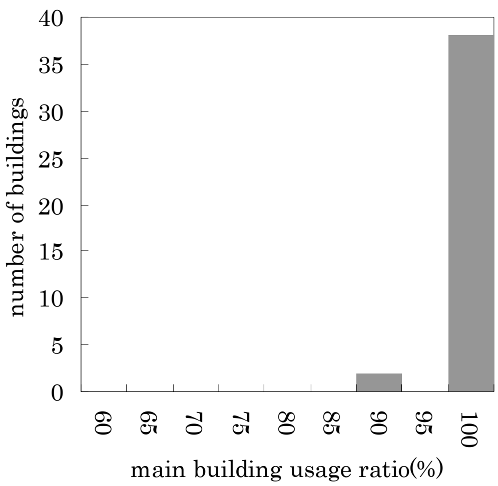
[D08]



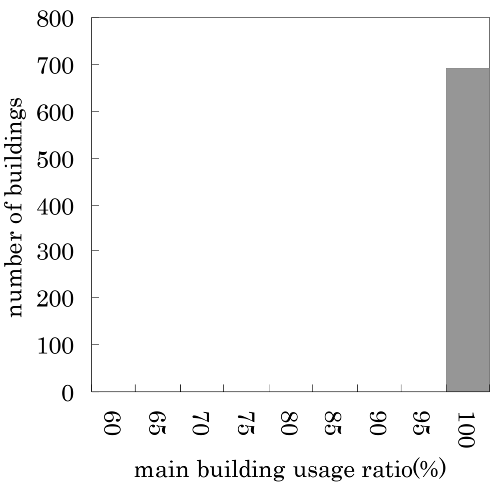
[D09]



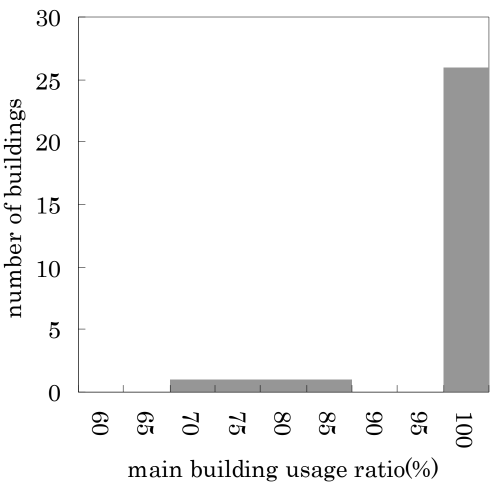
[D10]



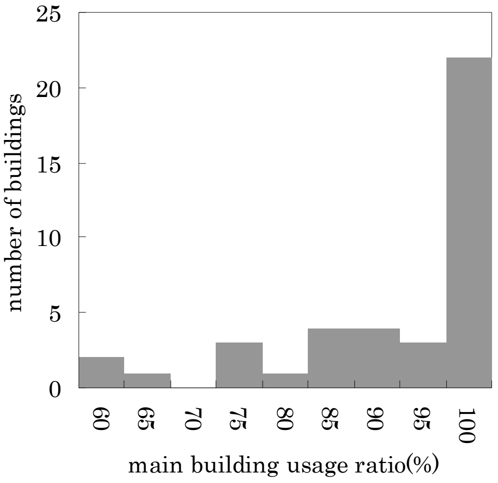
[D11]



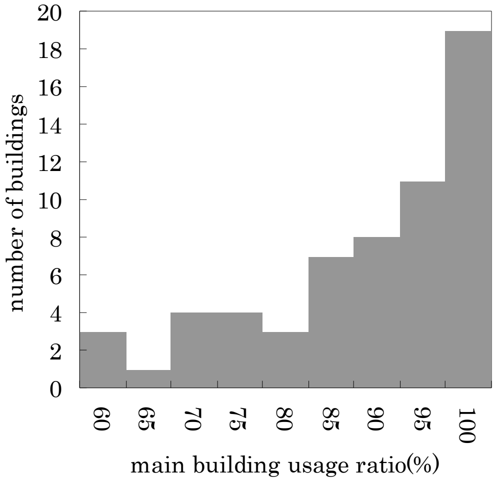
[D12]



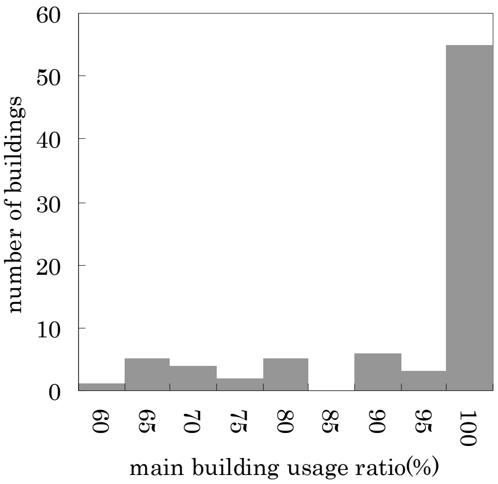
[D13]



[D14]



[D16]



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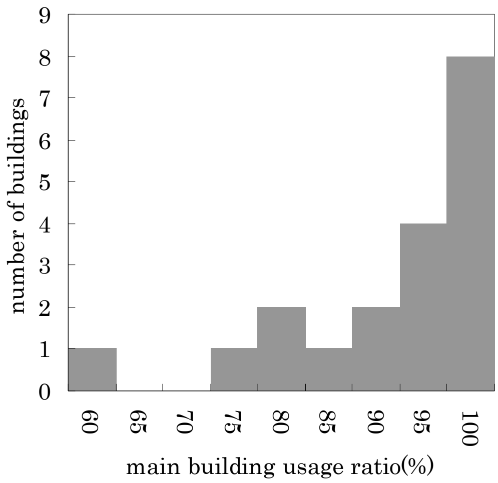

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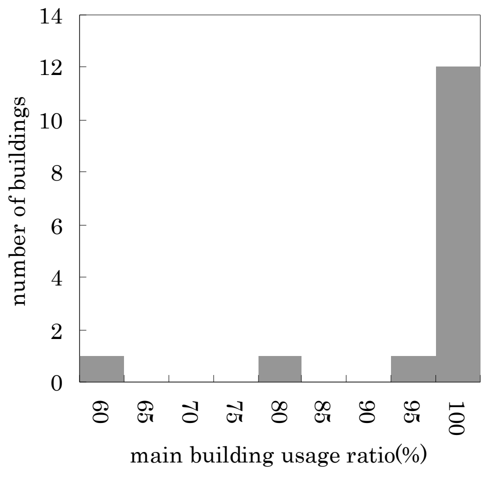
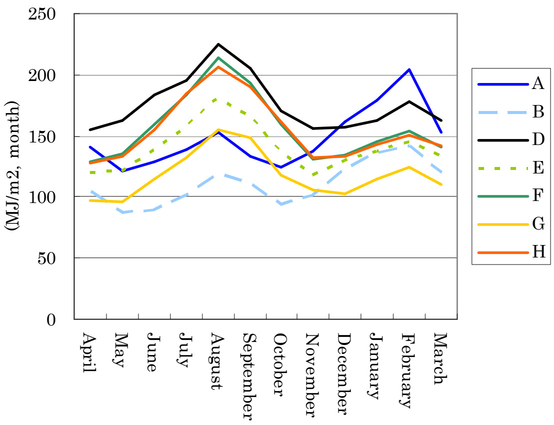


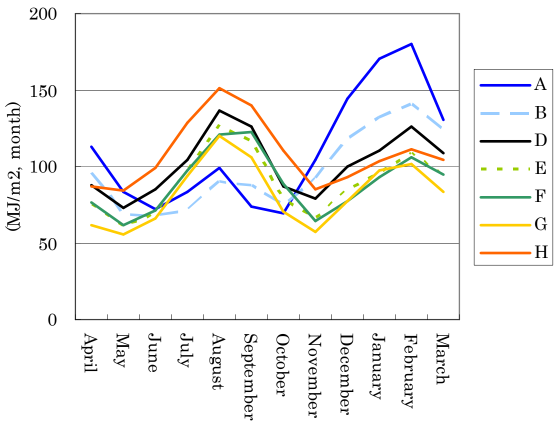
[D22]

Figure3.1.3-7 Main building use ratio of each building type

In the DECC survey, data of each building type are divided into 8 areas; A(Hokkaido), B(Tohoku), C(Hokushin'etu), D(Kanto), E(Chubu), F(Kansai), G(Shikoku/Chugoku), H(Kyushu). Monthly EUI from April 2006 to March 2007 for each building type and area are shown in Figure3.1.2-6. It shows that in most of building types 1) North area such as Hokkaido, Tohoku: Monthly EUI in winter season are larger than summer season. 2) South area such as Kyushu, Shikoku/Chugoku, Kansai, Kanto: EUI in summer season are larger than winter season. And on the other hand, educational buildings such as kindergarten, elementary school and shows another trend of fluctuation that EUI in summer season is flat even in south areas except Kyushu area.



[01]



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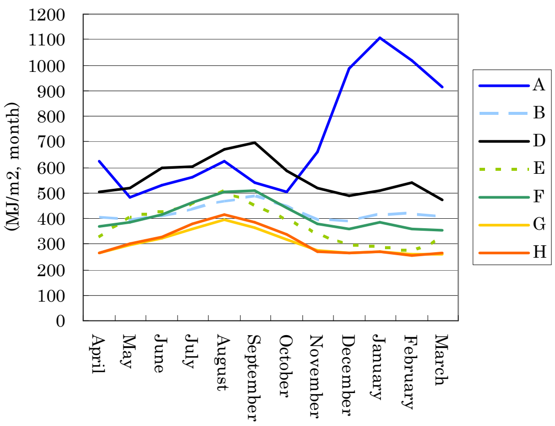

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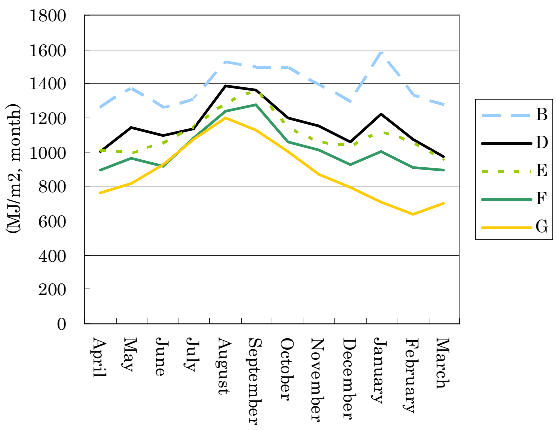

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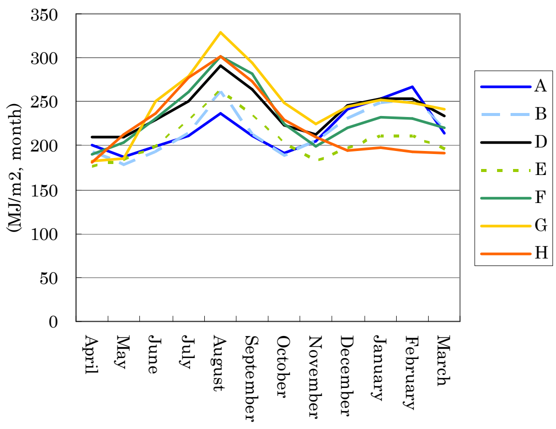

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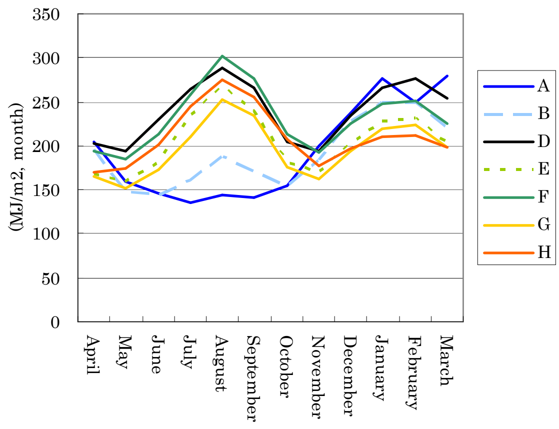

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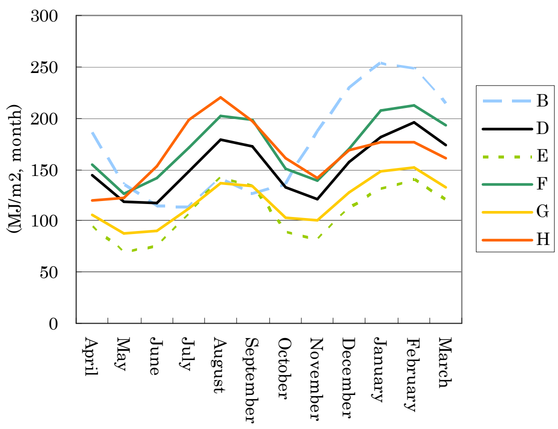

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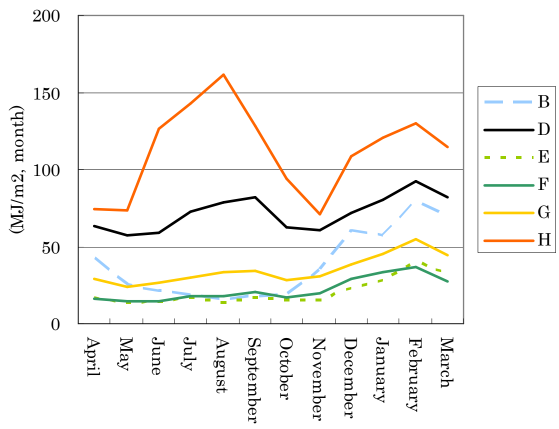
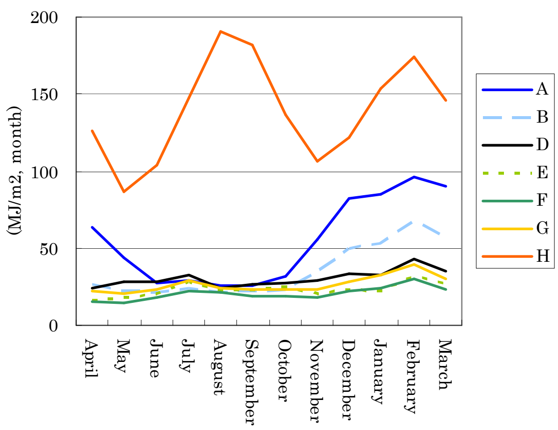


[11]



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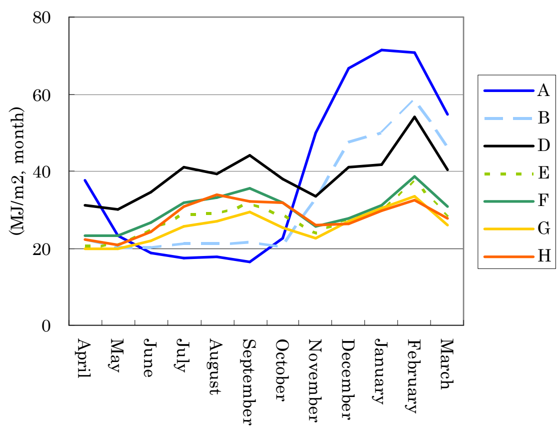

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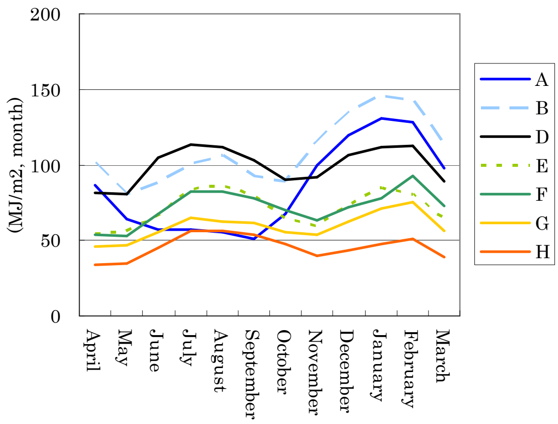

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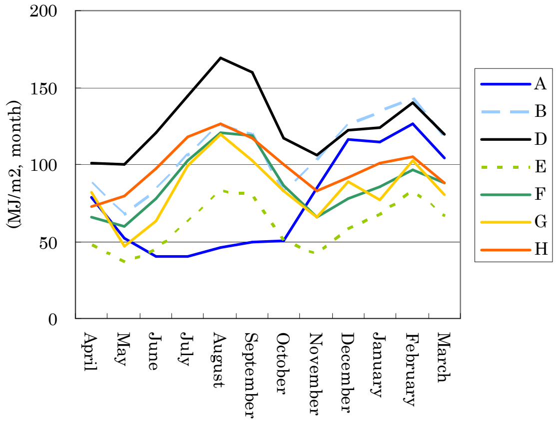

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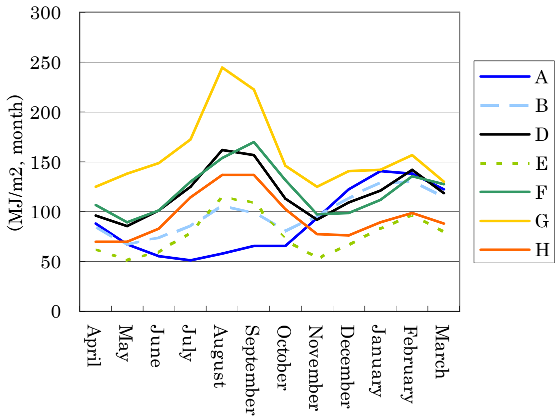

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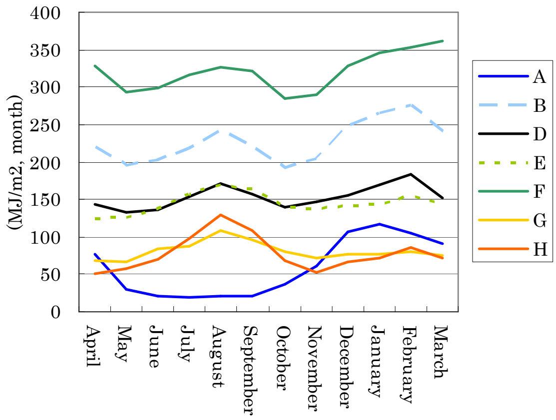


[18]

Figure3.1.3-8 Monthly EUI fluctuation (2007)

Actually, EUI of each area is different from points in the area. As an example, Monthly EUI for elementary school and (B12) and high school (B13) in prefectures of Tohoku area are shown in Figure3.1.3-9 and Figure3.1.3-10 and annual EUI is shown in Figure3.1.3-11. Monthly EUI are flat in summer season and there is little difference between prefectures. In winter season, EUI are increasing and there is large difference especially between Aomori prefecture and other prefectures.

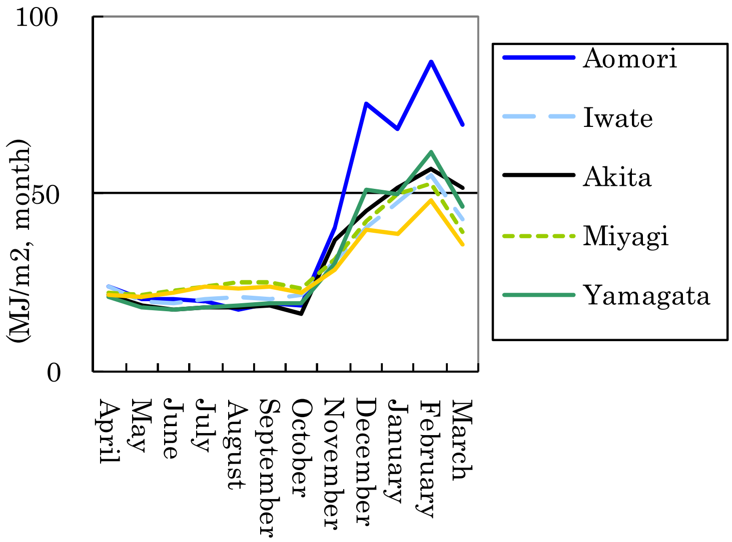


Figure3.1.3-9 Monthly EUI for elementary school in Tohoku prefectures (2007)

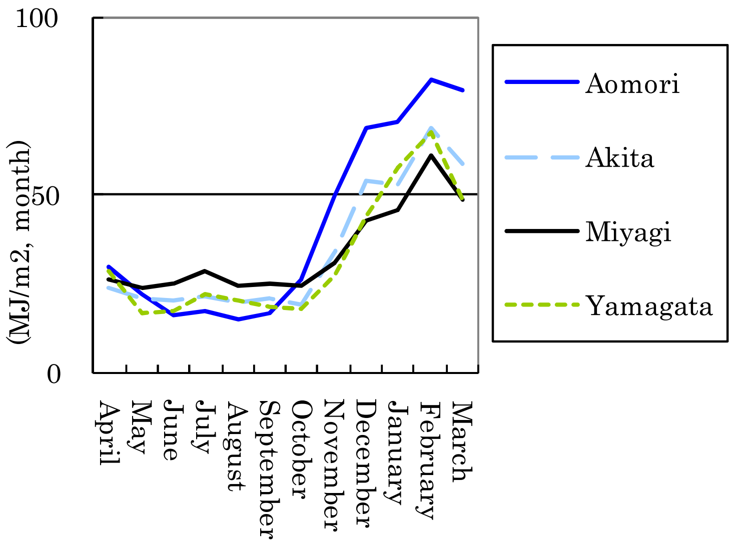


Figure3.1.3-10 Monthly EUI for high school in Tohoku prefectures (2007)

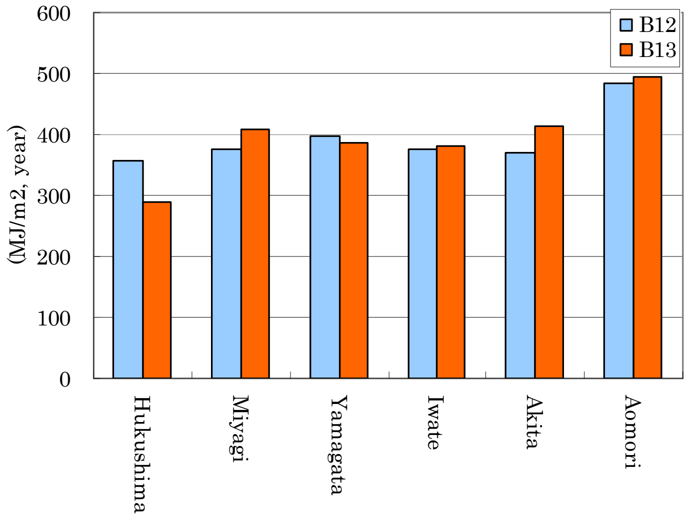


Figure3.1.3-11 EUI in prefectures of Tohoku area (2007)

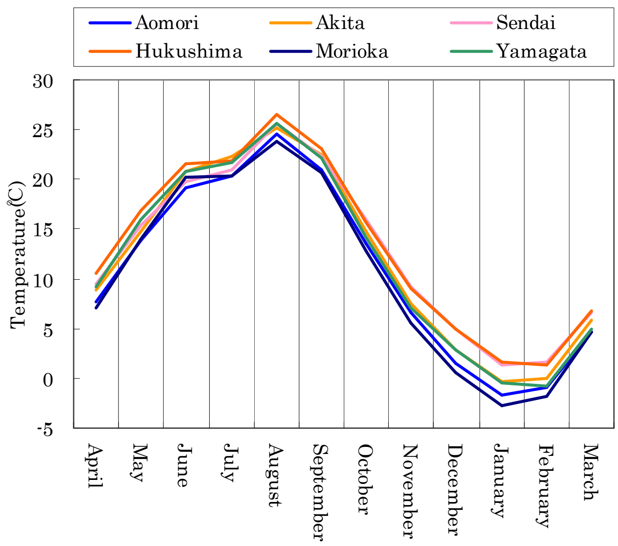


Figure3.1.3-12 Temperature in Tohoku area (2007)

Next, we examined annual variability of EUI by comparison of 2006 and 2007 EUI of same buildings. Difference of 2007 from 2006 is shown in figure3.1.3-13 box-and-whisker plot. EUI of most building types remain unchanged or slightly increased except sports gym (D18). Figure3.1.3-14 also shows average annual change of monthly EUI. EUI increased in most of month and most of building types. In addition, EUI widely increased in February and EUI remain unchanged only in July. Next figure3.1.3-15 shows change of monthly average temperature of Kanto area in 2006 and 2007. We can see that the change of EUI coincides with the change of temperature in some building types. Also, EUI of educational buildings including Elementary school (D13) and High school (D14) increased only in winter. From those results, it is considered that annual variability of same building is strongly caused by climate difference and following change of thermal load.

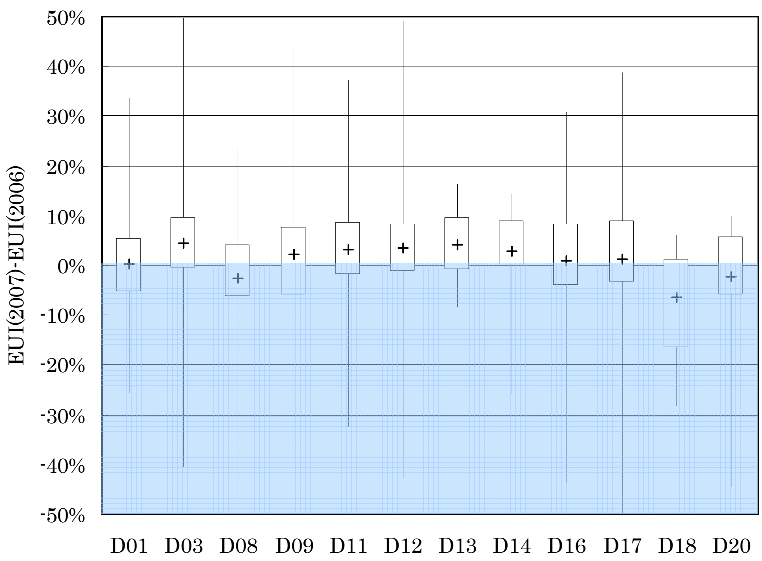


Figure3.1.3-13 2006 and 2007[D]

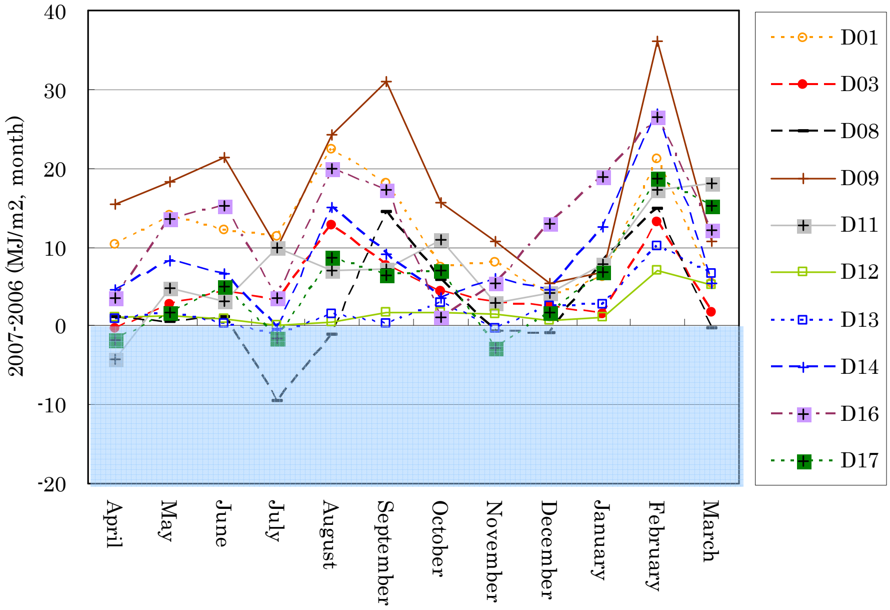


Figure3.1.3-14 2006 - 2007[D]

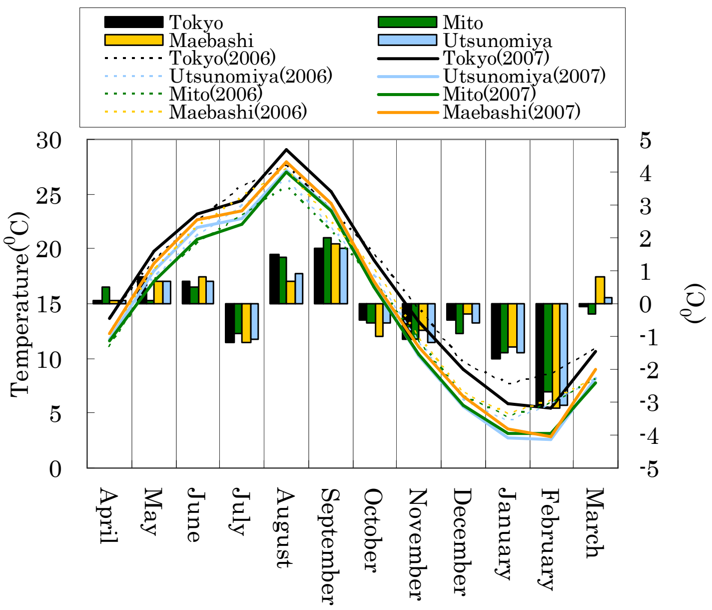


Figure3.1.3-15 2006 and 2007[D01]

3.1.4 Factor analysis of energy consumption

We examined factors of energy consumption of Office buildings. Level 2 data was used for analysis. Table3.1.4-1 shows examined 22 variables and correlation coefficient of EUI and 22 variables. Strong correlation was observed on Annual operating hour (X4) and Annual air-conditioning hours (X5).

Multiple linear regression method was used for estimation of EUI. Step-up procedure method was used for selection of variables. Variables including multicollinearity were removed before using step-up procedure method. Annual air-conditioning hour (X5) and Annual opening hours (X4) were adopted as explanatory variables and coefficient of determination was 0.558 (Table3.1.4-2).

Table3.1.4-1 Variables

Variable	Correlation coefficient	Variable name
X1	0.3507	Floor space
X2	0.2117	Floor number
X3	0.1636	Building age
X4	0.5431	Annual opening hours
X5	0.6996	Annual air-conditioning hours
X6	0.3718	Water consumption unit
X7	0.4586	Electricity capacity (kWh)
X8	0.4494	Electricity capacity (kVA)
X9	-0.2346	Cold energy capacity
X10	-0.2570	Heat energy capacity
X11	0.0113	Auxiliary power unit
X12	-0.1892	Private electricity cogeneration
X13	0.3858	Energy-saving measures
X14	0.2218	Energy-saving equipments
X15	0.0813	(Absorption and centrifugal chillers)
X16	0.2019	(Boiler)
X17	0.0972	(Absorption and centrifugal chillers)
X18	0.0344	(Heat pump)
X19	-0.0034	(Package)
X20	-0.1647	Exhaust heat recovery system
X21	0.0455	Heat storage tank
X22	-0.1210	Ice thermal storage tank

Table3.1.4-2 Variables

	Variable name	Standardized partial regression coefficient
X5	Annual air-conditioning hour	0.5833
X4	Annual opening hours	0.2308

R^2=0.558

Next, Tueky-Kramer's test was used to identify differences of EUI between groups. It is clarified that EUI are significantly different in some groups. Distributions of EUI of which statistical difference is determined as significant by Tueky-Kramer's test are shown in Figure3.1.4-1, 3.1.4-2, 3.1.4-3 and 3.1.4-4. SD is Standard Division and SE is Standard Error. Furthermore, multiple regression models were created for the groups of which difference were determined as significant.

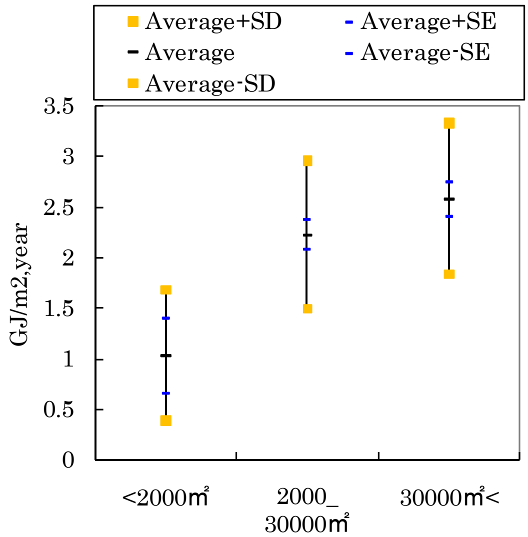


Figure3.1.4-1 Distribution of EUI divided by floor space

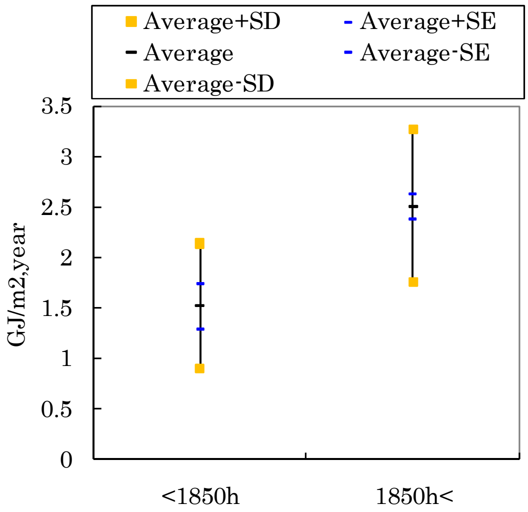


Figure3.1.4-2 Distribution of EUI divided by opening-hour

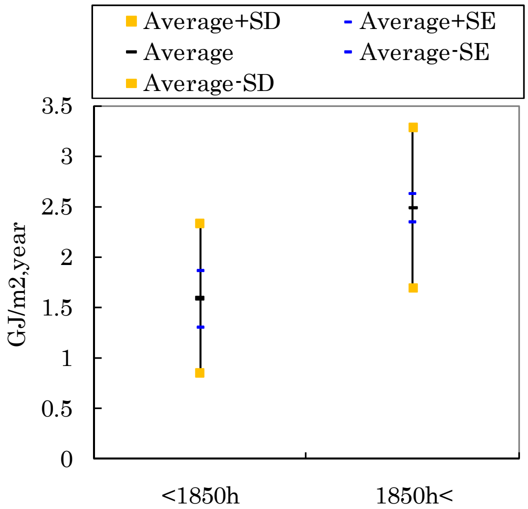


Figure3.1.4-3 Distribution of EUI divided by air-conditioning hour

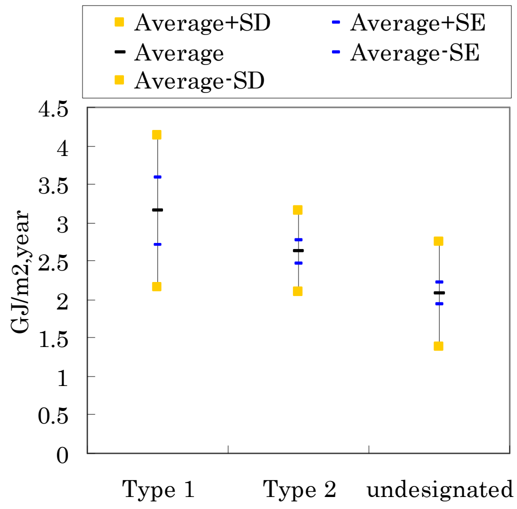


Figure3.1.4-4 Distribution of EUI divided by Designation of Energy Management Factory

An example which gives good prediction model is shown in following. In this case, multiple regression model was created for Type1 group. Annual air-conditioning hour (X5), Building age (X4) and Floor space (X1) were adopted as explanatory variables and coefficient of determination was 0.894 (Table3.1.4-3).

Table3.1.4-3 Variables

	Variable name	Standardized partial regression coefficient
X5	Annual air-conditioning hour	0.8734
X3	Building age	0.4241
X1	Floor space	0.2757

R^2=0.894

In addition, we examined effectiveness of estimation using Artificial Neural Network (ANN) model. 3 layer classified type network was used for ANN model. Back Propagation method was used for learning algorithm and Newton-Raphson method was used for optimization. The number of units in middle layer is determined by trial-and-error method. After the ANN model learning is finished, we examined effectiveness of ANN model using 10 Fold Cross Validation method. Prediction error is given as following formula;

$$E_{cv} = \frac{1}{n}\sum_{l=1}^{10}\sum_{i=1}^{n_l}(m^{(l)}(X_i^{(l)}) - Y_i^{(l)})^2$$

where n is number of sample and l is the number of group.

Actual EUI values and fitting values from both method are shown in Figure3.1.4-5. The multiple regression model is shown in Table3.1.4-3. The ANN model used 10 units in middle layer. Figure3.1.4-6 shows relation between explanatory variables and estimate values of multiple regression model and Figure3.1.4-7 shows that of ANN model. Naturally, the ANN model enable a more complex estimation compared to the multiple regression model. However, a result of 10 Fold Cross Validation method (Figure3.1.4-8) indicates that the created ANN model is inadaptable to new data.

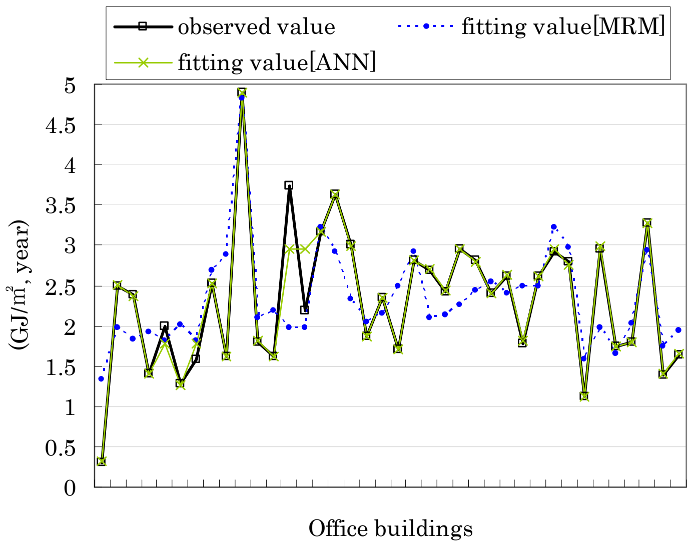


Figure3.1.4-5 Fitting values of liner regression and ANN model

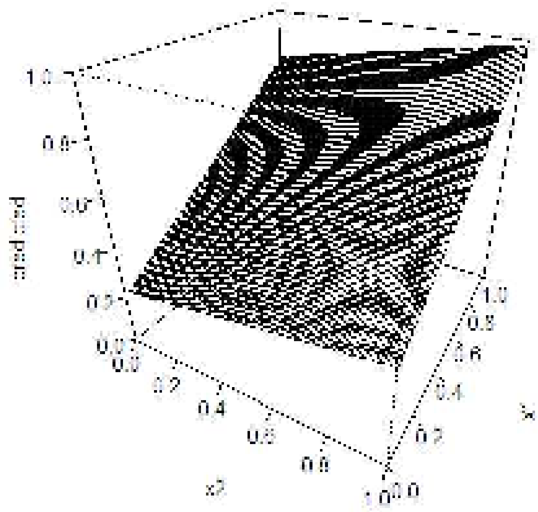


Figure 3.1.4-6 Estimate values of linear regression model

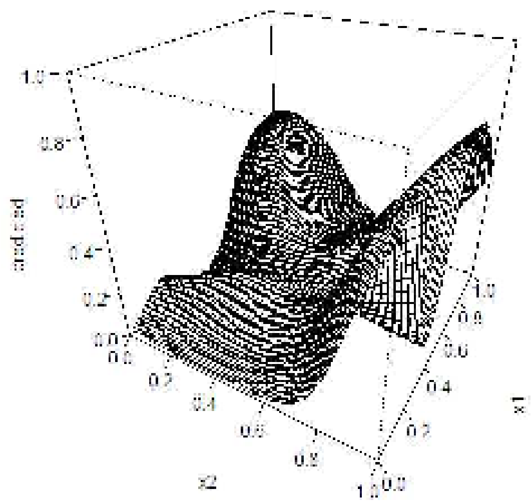


Figure 3.1.4-7 Estimate values of ANN model

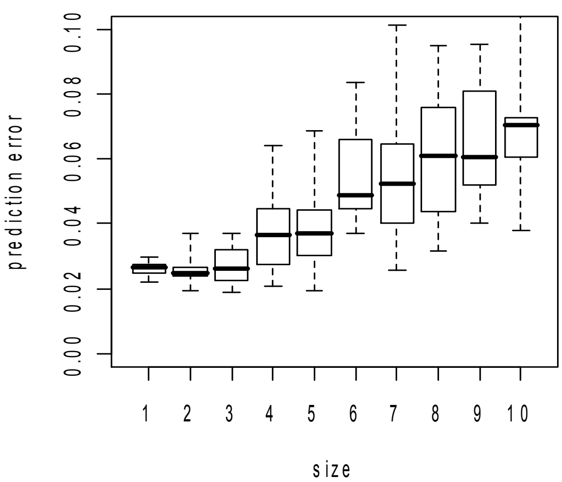


Figure3.1.4-8 Prediction error of ANN models consists of 1 to 10 units in middle layer

3.2 Actual performance of split air-conditioning system installed in commercial buildings

3.2.1 Outline of investigation

To clarify the actual performance of split air conditioning system, time-series data were collected by remote data collection system via internet and it was developed by an air conditioning apparatus maker. Introducing this system to building, the building owner is able to get detailed information about the system operation.
Various data of Indoor units and Outdoor units which are required to control of systems can be obtained from this collection system. Those system controlling data are useful to analyze the behavior of systems. In this study, we treat only the data, which are used to control systems and collected by remote data collection system. Using this system, it is not required any external measurement equipments, therefore measuring can be easy and it is able to measure the systems for the long term.

3.2.2 Collected data items

Table3.2.2-1 shows collected data items grouped into Outdoor unit and Indoor unit. All data items were collected as hourly interval data. The capacity of the air-conditioning system is calculated by the 'compressor curve method', which use a characteristic of a compressor flow rate. Measuring following items; High pressure, Low pressure, Condensing temperature and Evaporation temperature and assign it into regression model of compressor characteristic the capacity can be calculated. The Terms and its specifications used in this study are shown in Table3.2.2-2. To calculate the system COP, loss of defrost operation on winter and standby electric are included in electric power consumption of the system. Defrost operation occurs under the condition; outdoor temperature is lower than 4°C, and loss of the capacity is calculated as 40%.

Table3.2.2-1 Collected data items

	Data name	Unit	Specifications
OU	Data time	Hour	Hourly date
	Temperature	°C	Temperature of outdoor
	High pressure	Kgf/cm2G	Pressure of refrigerant
	Low pressure	Kgf/cm2G	Pressure of refrigerant
	Condensing temperature	°C	Temperature of refrigerant
	Evaporation temperature	°C	Temperature of refrigerant
	Operation time	Minute	Operated time of compressor
	Electric power consumption	kWh	
IU	Data time	Hour	Hourly date
	Intake temperature	°C	Measured at intake side
	Preset temperature	°C	Set by remote controller
	Operation time	Minute	Operated time of fan
	Thermo-on time	Minute	Time of thermal exchange mode
	Electric power consumption	kWh	

Table3.2.2-2 Designation

OU COP	Cooling, heating capacity / Electric power consumption of outdoor unit
System COP	Cooling, heating capacity / Electric power consumption of entire system
Thermal load	Cooling and heating capacity / Rated cooling and heating capacity

3.2.3 Outline of buildings for investigation

The number of the systems for investigation is 149 of 37 commercial buildings and data was measured from 2007 December 1st to 2008 November 30th. 103 out of 149 systems are installed in office buildings and others are apartment, school, hospital etc. (Figure3.2.2-3). Total rated capacities of systems of entire buildings are 10 to 100 HP (Figure3.2.3-2). Each Outdoor unit has minimum one indoor unit to maximum 15 indoor units.

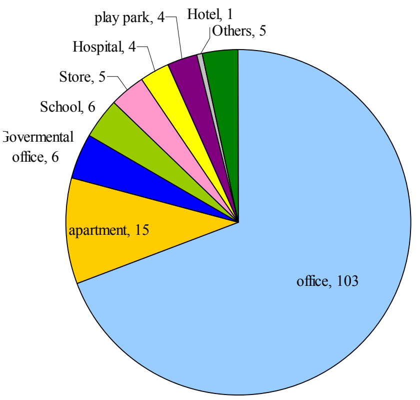


Figure3.2.3-1 Building use

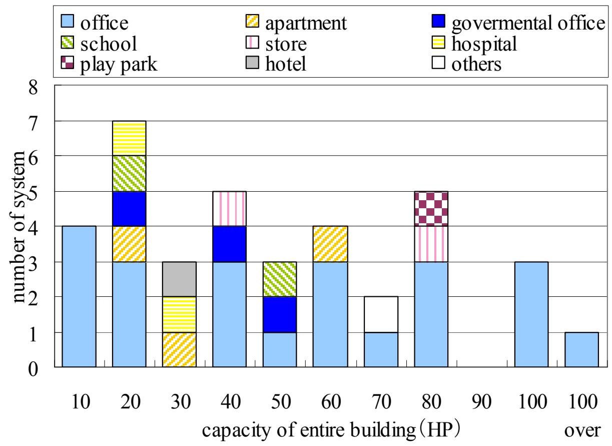
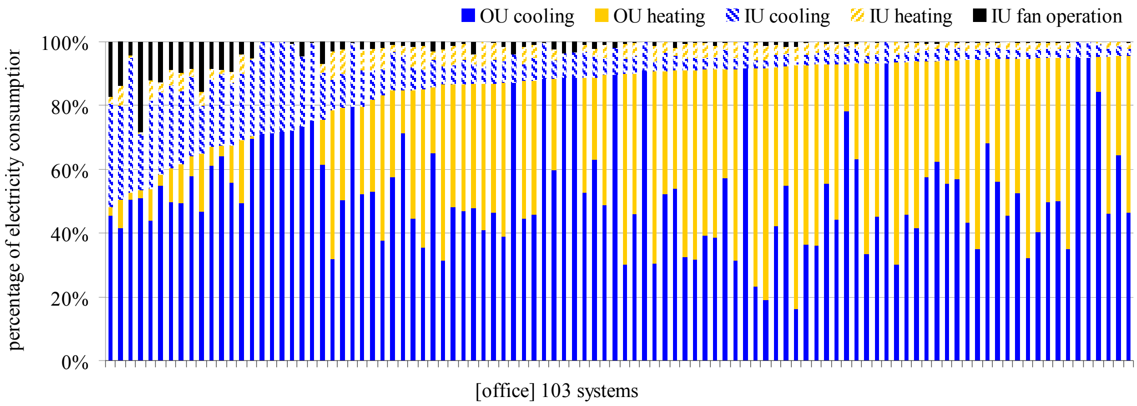


Figure3.2.3-2 Capacities of buildings

3.2.4 Results

3.2.4.1 Electric power consumption

At first, details of electric power consumption by the system have to be confirmed to clarify the characteristic of the systems. Electric power consumption can be divided by two units; outdoor unit and indoor units and the 3 operation modes; heating, cooling and fan operation. Figure3.2.4-1 shows the results of 149 systems installed in commercial buildings.



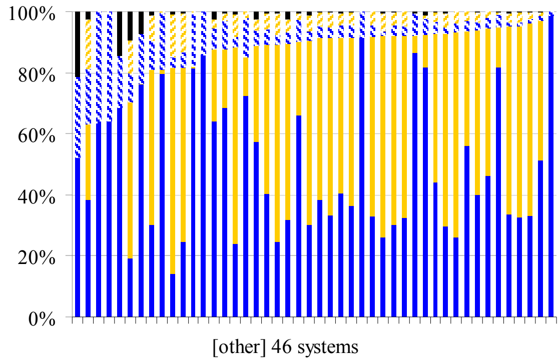


Figure3.2.4-1 Details of annual electric power consumption of 149 systems

In most of systems electric power consumption of outdoor units have large share in total electric power consumption and indoor units have only small share less than 10%. But in some systems, for example systems of No.35 building, electric power consumption of indoor units have large share in total electric power consumption. For this reason, two factors should be considered. First, the rated electric power consumptions of indoor units are very different by types of indoor units. Investigated 38 systems consists of 644 Indoor Units and the number of each types are shown in figure3.2.4-2. Second, outdoor units operate in low load and electric power consumptions of outdoor units are relatively small. Figure3.2.4-3 shows two example (No.34-1 and No.34-2) of Operation hours of Indoor Units.

No.34-1 consists of 3 Indoor Units, only single Indoor Units operate constantly and other 2 Indoor Units hardly operated thorough the year. No.34-2 consists of 4 Indoor Units, 2 Indoor Units operated constantly through the year but other two Indoor Units operated only in summer on cooling mode. As a result, Outdoor Units of those systems operated in low thermal load. Also in some systems especially No.37, electric power consumptions of fan operation mode have large shares. Figure3.2.4-4 shows fan operations occur during winter and spring in the case of No.37-3. Figure3.2.4-5 shows the system operates as both cooling and heating mode in low thermal load during winter. On this case, when the preset temperature was lower than the intake temperature in heating mode, outdoor unit stopped the operation and fan of indoor unit continued to operate without thermal exchange.

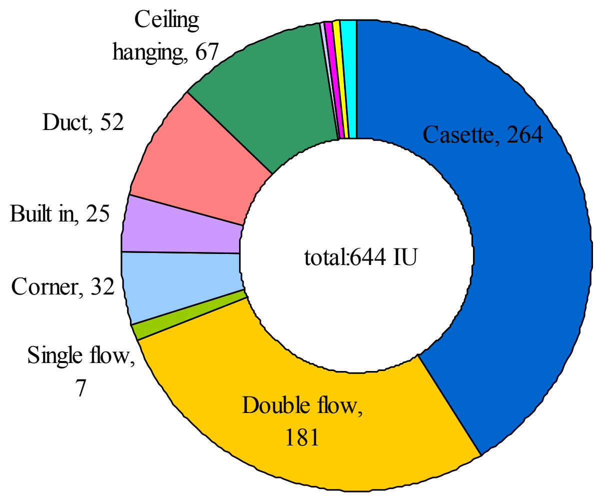


Figure3.2.4-2 Indoor Unit type

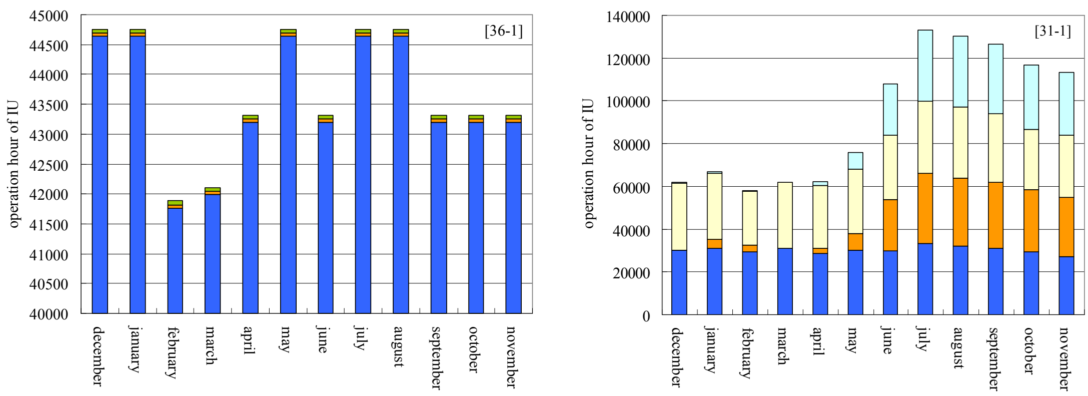


Figure 3.2.4-3 Operation hours of Indoor Unit

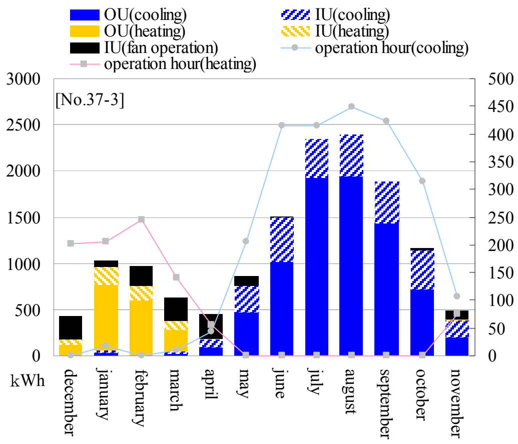


Figure3.2.4-4 Monthly electric power consumption of No.37-3

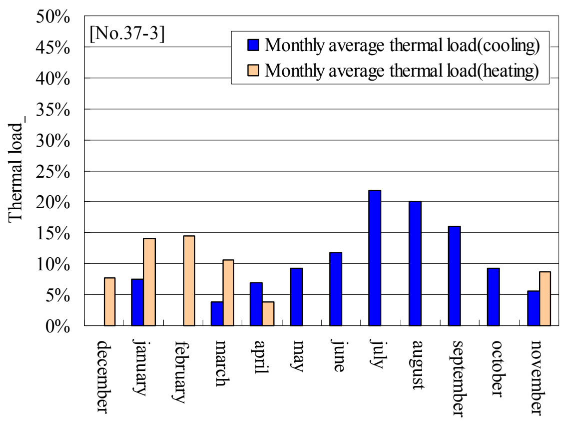


Figure3.2.4-5 Monthly thermal load of No.37-3

3.2.4.2 Annual average thermal load

As Figure3.2.4-6 and Figure3.2.4-7 show most of annual average thermal loads of heating were under 40 % and maximum thermal load doesn't reach to 100% in most systems. Especially, thermal loads of systems were low whose rated capacities are higher than 15HP. This result indicates thermal loads of systems are overestimated on design phase in many buildings. Annual average thermal loads and maximum thermal loads of cooling were higher than those of heating. Generally, cooling load is higher than heating load in office buildings because of office automation equipments such as PC. Also office buildings that contain data server need annual cooling operation and shown high thermal load.

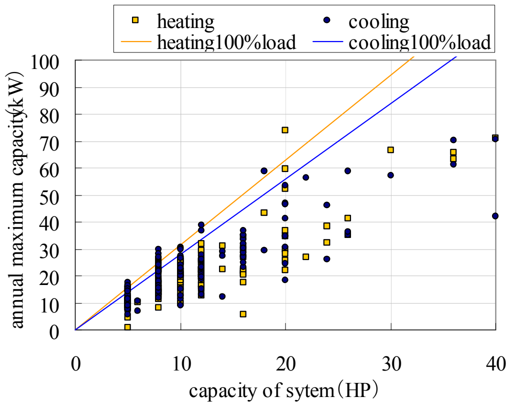


Figure3.2.4-6 Annual maximum thermal loads

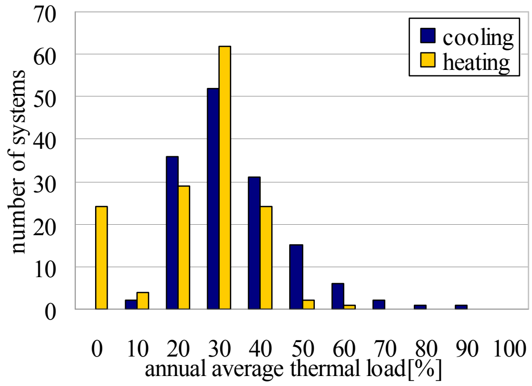


Figure3.2.4-7 Annual averages of thermal loads

3.2.4.3 Annual average COP

Figure3.2.4-8 shows histogram of annual cooling COP of all systems and Figure3.2.4-9 shows annual heating COP. In these two graphs grey outlined bar graph is OU COP and coloured bar graphs are system COP. The average of OU COP on cooling mode was 3.4 and system COP was 2.8 and OU COP on heating mode was 3.1 and system COP was 2.3. Analysing system COP, following factors should be considered; 1) Relation between thermal load and capacity, 2) type of indoor unit, 3) Operation behaviour of indoor units.

1) Generally, the relation between thermal load and cooling and heating capacity is such trend shown on figure3.2.4-10 which is the result of annual operation of a system No.25-1. Figure3.2.4-10 shows COP decreases when thermal load is low, and at the same time such systems shows lower system COP because thermal load is small and electric power consumption of indoor units is relatively large in those cases. Also COP of heating operation is lower than COP cooling operation because of defrost operation.

2) There are various types of indoor units and its electric power consumptions are very different. Especially rated electric power consumptions of the types such as 'under floor air supply' or 'lowboy' are larger compared with other types.

3) An indoor unit operates differently because of switch on-off, preset temperature and short circuit with neighbour indoor units. We consider about short circuit of indoor units on chapter3.4.

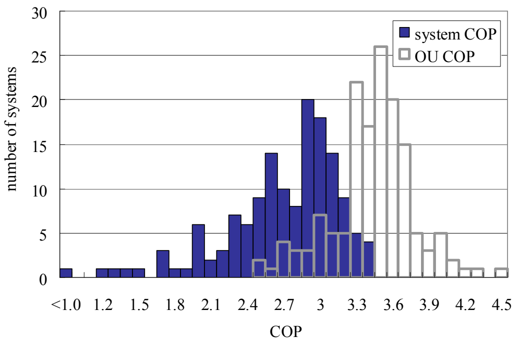


Figure3.2.4-8 COP on cooling mode

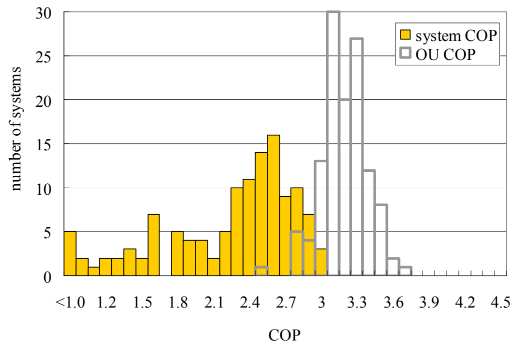


Figure3.2.4-9 COP on cooling mode

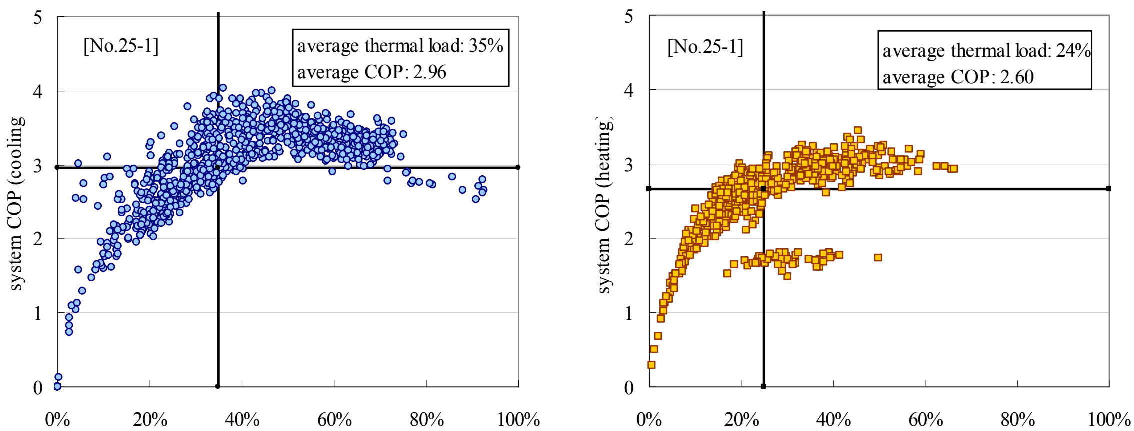


Figure3.2.4-10 Relation between thermal load and system COP on a case of No.25-1

3.2.4.4 Short circuit between indoor units

We clarify more detailed behavior of indoor units by a case study. We analyze a system installed in an office building; No.24-1 for example. This system has 4 indoor units connected to an outdoor unit. In this study, actual thermal load of buildings are unknown, so thermo-on time of indoor units are used as indicater of thermal load. Figure 3.2.4-11 shows average of thermo-on time of cooling operation by each temperature and preset temperature. In case of the IU.1, when temperature is higher than 30°C, average thermo-on time reaches 60 minutes per hour as maximum. On the other hand, case of the IU.2, maximum of thermo-on time is only 30 minutes. From this results, it is likely that thermal load of IU.2 is lower than IU.2. For this reason, the short circuit between two indoor units should be considered as one of the factor.

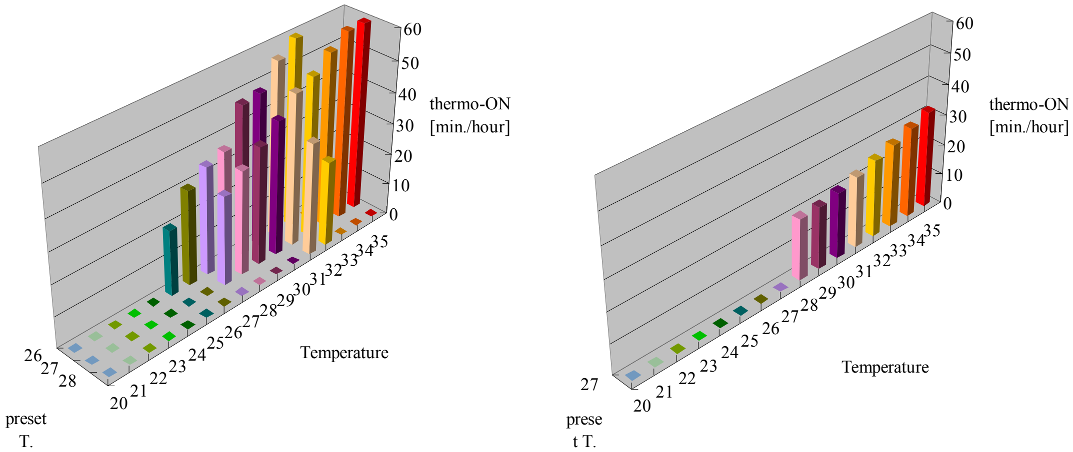


Figure3.2.4-11 Average of thermo-on time by temperature and preset temperature
(Left: IU.1, right: IU.2)

Figure3.2.4-12 shows operated hours grouped by the number of concurrent operating indoor units. IU.2 operated concurrently with IU.1 most of time from July to September. Next Figure3.2.4-13 show thermo-on time grouped by number of operated indoor units. In IU.2 case thermo-on times distribute smaller level when indoor units operated concurrently. From these results, the short circuit between indoor units is important factor of thermo-on time of indoor units and thermal load of the system.

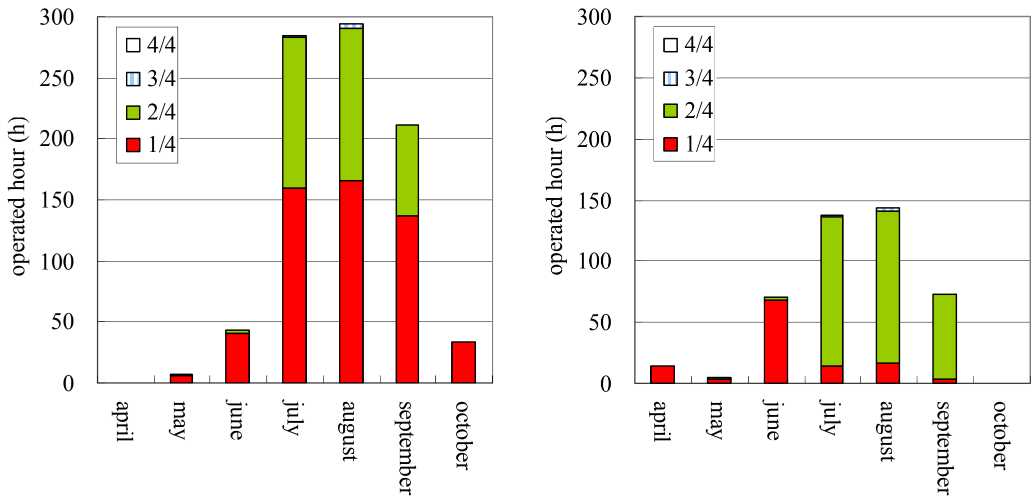
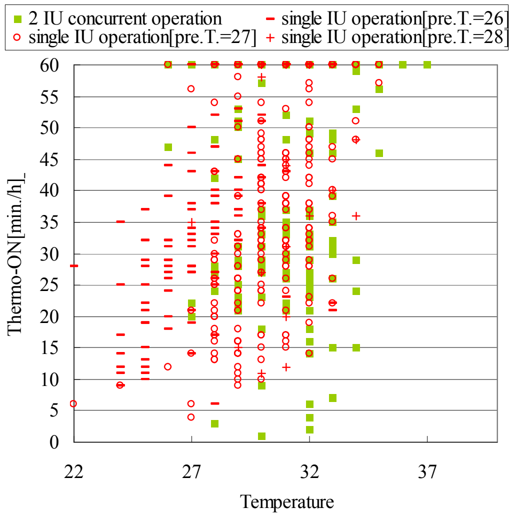


Fig3.2.4-12 Operation hour by number of concurrent operation
(Left: IU.1, right: IU.2)



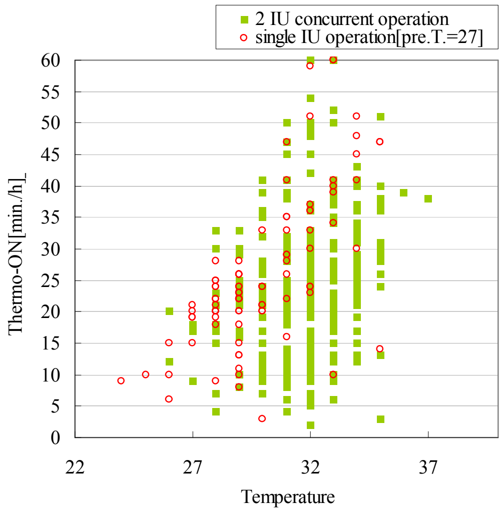


Figure3.2.4-13 Thermo-on time and temperature by number of concurrent operation (Left: IU.1, right: IU.2)

4. Conclusion

In this study, the structure of DECC and the surveys method and the results of surveys are shown, and we examined required database construction for utilization to energy-reduction measurements. DECC is divided into 3 levels; Basic database, Standard database, Detail database and the result of each database are shown. As the result of Basic database, Energy Use Intensity (EUI) for each building type and area are calculated and classification of building types is reconsidered as follow;

1) Some building types should be divided by size of floor space. (Ex. Department store, Office, Food service)

2) Some other building types usually include other building usage and it is required to be classified by ratio of building usage. (Ex. Office, Sports gym, complex)

3) EUI is different according to areas and even prefectures area so the classification should depend on climate conditions.

4) Sample size determination should comply the framework of reconsidered classification as discussed above.

Furthermore, the method of survey should be adjusted to the renewed classification of building types. Proposed more detailed classification requires more detailed information about buildings such as floor space and building ratio before sending the questionnaires.

In the results of standard database, we examined a multiple linear regression model and conducted an analysis of variance for factor analysis of energy consumption. Furthermore, Artificial Neural Network (ANN) model was examined for prediction of EUI. Although ANN model gives more accurate prediction than the multiple linear regression model, it was difficult to make an usable model for new data. From the results, it is considered that more detailed data items of buildings such as thermal insulating properties and energy end- use are required for the proper model.

At last, the results of actual performance of split air-conditioning system installed in commercial buildings are shown as an example of Detail database. We investigated actual operations of air split conditioning systems installed in commercial buildings. From the results, it was clarified that the necessary capacities of systems are overestimated at the design phase and many systems are operated with a low thermal load. The system COP can be improved by installing smaller systems to the buildings. Also it is necessary to take actual operation behaviour of each indoor unit into consideration. Thermal load of systems can be improved by installing proper combination of indoor units and outdoor units. It was confirmed that the short circuit of indoor units is the important factor of thermal load and system COP. There are some possible measures to improve the system COP of those systems. 1) Stop fan operation to reduce electric power consumption by indoor units while thermo-off. 2) Put restriction to change preset temperatures to improve short circuit between indoor units to improve the system COP. It is required to evaluate the improvement of the performance by those measures for further studies.

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Appendix

Questionnaires

1) 2007 level 1 survey

2) 2008 level 1 survey

調査票

建物名称，住所，ご氏名等は，一切公開いたしません．

貴社名称　：

記入者ご所属（部・課等）　：

記入者ご氏名　：　　電話　（　　）　　E-mail:

1. 建物概要（建物が複数棟ある場合は、用紙をコピーして建物単位でお書き下さい）

建物名		所有形態		□自社ビル	□貸しビル
所在地	〒				
延床面積	駐車場を除く　㎡	駐車場面積	㎡	階　数	地上　階、地下　階
敷地面積	㎡	建築面積	㎡	竣工年月	年　月
営業時間	表玄関（入口）が開いている時間をお書き下さい。	平日　h/日	土曜　h/日		日曜　h/日
空調期間	冷房　月　日 ～　月　日	暖房　月　日 ～　月　日		契約電力量	kW

2. 延床面積に含まれる建物用途比率

□①事務所	%	□⑧住居	%
□②官公庁（税務署、警察署、地方公共団体の支庁などを含む）	%	□⑨劇場・ホール（会議場、集会場などを含む）	%
□③デパート・スーパー・店舗（コンビニ・小売店など）	%	□⑩展示施設（図書館、博物館などを含む）	%
□④飲食店	%	□⑪スポーツ施設	%
□⑤ホテル・旅館（客室数　　室）	%	□⑫福祉施設（老人ホーム、身体障害者ホーム含む）	%
□⑥病院（大学病院などを含む）・診療所（ベッド数　　床）	%	□⑬電算・情報センター	%
□⑦学校（保育所や幼稚園を含む）	%	□⑭その他（　　　）	%

注）　・店舗に付随する事務所・設備等は店舗として扱い、①から⑭の該当するものにレ印を記入して下さい。
・（わからない場合は、記入しなくても構いません）概略面積比率%、「⑤ホテル」や「⑥病院」を選択した時は、客室数やベッド数を記入して下さい。

3. エネルギー・水消費量に関するご質問

月別でご記入される場合　⇒　（裏面へお進み下さい）

年間値でご記入される場合　⇩

注）　・2006 年度とは、2006 年 4 月～2007 年 3 月の期間を指します。
・該当しないものは空欄にしておいて下さい。また単位が異なる場合は適宜ご自身でご修正下さい。
・過去のご自身のエネルギー消費量について記録をお持ちでない場合、ご契約中の電力・ガス会社に問い合わせることで入手できる場合があります。エネルギー会社の連絡先は検針票などに記載されております。
・「都市ガス」「LPG」「石油系燃料」は、該当するものに○をお付け下さい（わかる範囲で結構です）。
・以下の種別以外の項目がある場合は、裏面の「その他」の欄にご記入下さい。

種　別	電　力	内訳（わかれば） 昼間	内訳（わかれば） 夜間	都市ガス 13A・12A・6A・5C・L1・L2・L3・他（　）	LPG い号・ろ号・は号
単位	kWh/年	kWh/年	kWh/年	m^3/年	m^3/年
2006年度					

種　別	石油系燃料 （A・B・C）重油 灯油・他（　）	地域熱供給（単位に○をお付け下さい） 冷　水	温水（温熱）	直接蒸気	上水消費量
単位	㍑/年	MJ/年・GJ/年	MJ/年・GJ/年	MJ/年・GJ/年	m^3/年
2006年度					

（下記の問について、あてはまるものに○をお付け下さい）

①上記エネルギー・水消費量について［（複数棟ある場合）敷地内建物全体・単体建物全体・単体建物の一部］**である。**

②電力消費量や都市ガスなどの月別消費内訳（熱源機器用、電灯ｺﾝｾﾝﾄ用など）を一部でもデータとして把握している。

はい・いいえ

ご協力ありがとうございました。

「月別でご記入」

注）・該当しないものは空欄にしておいて下さい。また単位が異なる場合はご修正下さい。

・過去のご自身のエネルギー消費量について記録をお持ちでない場合、ご契約中の電力・ガス会社に問い合わせることで入手できる場合があります。エネルギー会社の連絡先は検針票などに記載されております。

・「都市ガス」「LPG」「石油系燃料」は、該当するものに○をお付け下さい（わかる範囲で結構です）。

種　別	電　　力			都市ガス	LPG	石油系燃料	地域熱供給 （単位に○をお付け下さい）			上水 消費量	その他１	その他２
		内訳（わかれば）		13A・12A・6A 5C・L1・L2・L3 他（　　　）	い号 ろ号 は号	（A・B・C）重油 灯油 他（　　　）						
		昼間	夜間				冷　水	温水(温熱)	直接蒸気			
単位	kWh/月	kWh/月	kWh/月	m^3/月	m^3/月	ｷﾛﾘｯﾄﾙ/月	MJ/月・ GJ/月	MJ/月・ GJ/月	MJ/月・ GJ/月	m^3/月 or m^3/２ヶ月		
2006年　４月												
2006年　５月												
2006年　６月												
2006年　７月												
2006年　８月												
2006年　９月												
2006年 10月												
2006年 11月												
2006年 12月												
2007年　１月												
2007年　２月												
2007年　３月												
合計（年間値）												

（下記の問について、あてはまるものに○をお付け下さい）

①上記エネルギー・上水消費量について〔（複数棟ある場合）敷地内建物全体・単体建物全体・単体建物の一部〕**である。**

②電力消費量や都市ガスなどの月別消費内訳（熱源機器用、電灯ｺﾝｾﾝﾄ用など）を一部でもデータとして把握している。はい・いいえ

ご協力ありがとうございました。

平成 20 年度

エネルギー消費量に係わる基礎調査票

本調査は、緊急の課題である二酸化炭素排出量の削減に対して、建築物に起因するエネルギー消費量の把握が重要であるとの考えから、国土交通省の支援を受け（財）建築環境・省エネルギー機構内に設置された「非住宅建築物環境関連データベース検討委員会」が実施するものです。送付および回収は全国の大学・研究機関が担当しております。*質問項目には一部専門的な内容が含まれますので、建物を管理する技術者がいらっしゃる場合は、その方とご相談の上ご記入下さい。*
本委員会は、昨年度も同様の調査を実施しております。省エネルギー対策の進展や経年変化を把握するため、昨年度調査にご協力頂いた建物も、平成 19 年度の最新の情報でご回答くださいますようお願い申し上げます。また、本調査に関するご質問・お問い合わせは、下記「貴建物の調査担当連絡先」にお願い致します。

ご回答・ご提供いただきました内容につきましては、建物名称や住所などの詳細な情報は一切公開せず、地球温暖化防止のための政策立案、研究・開発活動の基礎的なデータとして、匿名化したものを利用させていただきます。

貴建物の調査担当連絡先

0000 大学 00 部 00 科　0000 研究室
〒000−0000
ＴＥＬ：００（0000）0000　　ＦＡＸ：００（0000）0000
調査担当者：0000（）
E-mail:

以下より、ご記入下さい

ご記入者のご所属に関する記入欄

ご記入年月日：平成２０年　　月　　日
貴社名称：
ご記入者ご所属（部・課等）：
ご記入氏名：　　　　　　　　　　　　電話　　　　（　　　）
E-mail:

A　建物概要に関するご質問（該当する建物が複数棟ある場合は、その合計値でご記入下さい）

建物(施設)名称		所有形態	□自社ビル　□貸しビル・その他			
所在地	〒					
延床面積	屋内駐車場を除く　㎡	竣工年月	年　月	階　数	地上　階、地下　階	
屋内駐車場面積	㎡	敷地面積	㎡			
営業時間	表玄関（入口）が開いている時間をお書き下さい。	平日　h/日	土曜　h/日	日曜　h/日		
冷暖房期間	冷房	月　日～　月　日	暖房	月　日～　月　日	契約電力	kW
冷暖房設定温度	冷房設定温度	℃	暖房設定温度	℃		
利用者数	常時入居している利用者数（従業員、教職員、学生など）	人	一時的利用者数（来客数、来場者数など）	人/日		

B　建物用途（上記「延床面積」に含まれる用途）の概略面積比率に関するご質問

概略面積比率とは、上記「延床面積」を100%とした場合の比率です。
概数で構いませんので、含まれる用途について全てご記入下さい。

注１）店舗に付随する事務所は店舗として扱って下さい。
注２）わかる場合は、関連する用途の客室数やベッド数をご記入下さい。

事務所注１）	%	病院注２）（大学病院・診療所などを含む）　（ベッド数　　床）	%
電算・情報センター	%	福祉施設	%
官公庁（税務署、警察署、地方公共団体の支庁などを含む）	%	幼稚園・保育園	%
ホテル・旅館注２）　(客室数　　室)	%	小学校・中学校	%
デパート・スーパー	%	高等学校	%
コンビニ	%	大学・専門学校	%
家電量販店（都心・郊外）	%	研究機関	%
郊外大型店舗（スーパー、家電量販を除く）	%	劇場・ホール（会議場・集会場などを含む）	%
その他物販	%	展示施設（図書館・博物館などを含む）	%
飲食店（和食・中華・洋食・その他）	%	スポーツ施設	%
住居	%	その他１（　　　　　　）	%

C　エネルギー・水消費量データに関するご質問

C-1　D-2でご記入頂くエネルギー・水消費量データについて、以下の当てはまる項目にレ印をご記入下さい。

□　（複数棟ある場合）敷地内建物全体のデータである。
□　単体建物全体のデータである。
□　単体建物の一部のデータである。

C-2　電力やガスなどの取引会社と検針日についてご記入下さい。

	取引会社名	検針日（該当するところに○を付けて下さい）		
電力		初旬・中旬・下旬	特に決まっていな	分からない
ガス		初旬・中旬・下旬	特に決まっていな	分からない
地域冷暖房		初旬・中旬・下旬	特に決まっていな	分からない

C-3　貴建物の電力消費量やガス消費量などのデータは、ＢＥＭＳ（Building Energy Management System）などの管理システムで管理されておりますか？　どちらかに○を付けて下さい。

はい　・　いいえ

D　熱源機器・エネルギー・水消費の実態に関するご質問

D-1　熱源機器と冷暖房エネルギー源について番号○印をつけ、［　／　］内は適当な選択肢に○印をつけて下さい。

熱源機器（複数回答：可）	熱源方式	1.ボイラ　2.電動冷凍機　3.空気熱源ﾋｰﾄﾎﾟﾝﾌﾟ（中央式）　4.空気熱源ﾋｰﾄﾎﾟﾝﾌﾟ（ﾊﾟｯｹｰｼﾞ）　5.水熱源ﾋｰﾄﾎﾟﾝﾌﾟ（中央式）　6.水熱源ﾋｰﾄﾎﾟﾝﾌﾟ（ﾊﾟｯｹｰｼﾞ）　7.ｶﾞｽｴﾝｼﾞﾝﾋｰﾄﾎﾟﾝﾌﾟ　8.吸収式冷凍機　9.冷温水発生機　10.その他(　　　)
	暖房エネルギー源	1.電気　2.都市ｶﾞｽ　3.LPｶﾞｽ　4.灯油　5.軽油　6.重油［A／B／C］
	冷房エネルギー源	1.電気　2.都市ｶﾞｽ　3.LPｶﾞｽ　4.灯油　5.軽油　6.重油［A／B／C］
	蓄熱槽	1.有り[水／氷]：　蓄熱槽容量（　　　　）m^3　　2.　無し

2

D-2　2007 年度のエネルギー・水消費量注1)

下記表の該当する種別の欄に、月別消費量をご記入下さい。該当しない種別の欄は空欄にしておいて下さい。
　また、月別消費量がご不明の場合は、「合計（年間値）」の欄に年間消費量をご記入下さい。

注１）2007 年度（2007 年 4 月～2008 年 3 月）のエネルギー・水消費量（金額ではありません）についてご記入下さい。
注２）該当するものに○をお付け下さい。
「①:領収書・請求書によるデータ」
「②:管理者がメータを読み取り記録しているデータ」
「③:建物に設置されている管理システムの計量計測データ」
注３）該当する単位にレ印をご記入下さい。また、該当する単位が無い場合は、ご修正下さい。
注４）「都市ガス」「LPG」「石油系燃料」は、該当するものに○をお付け下さい（わかる範囲で結構です）。
注５）自家発電量や中水、井水利用量などをご記入下さい。ご記入される場合は、単位もご記入下さい。
注６）過去のご自身のエネルギー消費量について記録をお持ちでない場合、ご契約中の電力・ガス会社に問い合わせることで入手できる場合があります。エネルギー会社の連絡先は検針票などに記載されております。

種　別	電　力			都市ガス注4)	LPG 注4)	石油系燃料注4)
		内訳（わかれば）		13A・12A・6A 5C・L1・L2・L3 他（　　　）	い号 ろ号 は号	(A・B・C) 重油 灯油 他（　　　）
		昼間	夜間			
データの記録元注2)	①・②・③	①・②・③	①・②・③	①・②・③	①・②・③	①・②・③
単位注3)	□ kWh/月 □ MWh/月	□ kWh/月 □ MWh/月	□ kWh/月 □ MWh/月	m3/月	m3/月	□ ﾘｯﾄﾙ/月 □ ｷﾛﾘｯﾄﾙ/月
2007年　4月						
2007年　5月						
2007年　6月						
2007年　7月						
2007年　8月						
2007年　9月						
2007年 10月						
2007年 11月						
2007年 12月						
2008年　1月						
2008年　2月						
2008年　3月						
合計（年間値） （合計値のみでも構いません）						

種　別	地域熱供給			水消費量	その他１注5) （　　　）	その他２注5) （　　　）
	冷　水	温水(温熱)	直接蒸気			
データの記録元注2)	①・②・③	①・②・③	①・②・③	①・②・③	①・②・③	①・②・③
単位注3)	□ MJ/月 □ GJ/月	□ MJ/月 □ GJ/月	□ MJ/月 □ GJ/月 □ t/月	□ m3/月 □ m3/2 ヶ月		
2007年　4月						
2007年　5月						
2007年　6月						
2007年　7月						
2007年　8月						
2007年　9月						
2007年 10月						
2007年 11月						
2007年 12月						
2008年　1月						
2008年　2月						
2008年　3月						
合計（年間値） （合計値のみでも構いません）						

3

D-3　冷房は建物の全室対象ですか、それとも一部の部屋のみでしょうか。番号一つに○を付けて下さい。

１．建物全室冷房　　２．一部の部屋のみ冷房（応接室・役員室・校長室・食堂など）

→ ２の場合、右欄に冷房室名を列挙してください。[　　　　　　　　　　　　　　　　　　　　　　　　]

E．省エネルギー等への取り組みに関するご質問

E-1　現在、貴建物では省エネルギーを推進されていますか。当てはまる番号一つに○を付けて下さい。

１．数値目標を定めて推進している　２．数値目標はないが､推進を心がけている　３．特に推進していない

――＞１．２．に○を付けられた場合、その内容はどのようなものですか。具体的にご記入下さい。

E-2　現在、省エネルギー対策として貴建物において取り組んでおられること、今後取り組めることはありますか。
それぞれの対策項目について当てはまる番号一つに○を付けて下さい。

対策項目	現在			今後		
	積極的に取り組んでいる	ある程度取り組んでいる	取り組んでいない	積極的に取り組める	ある程度取り組める	取り組めない
冷暖房温度の適正化	1	2	3	4	5	6
冷暖房の開始時期や終了時期の調整	1	2	3	4	5	6
不用な照明の消灯	1	2	3	4	5	6
使用していないＯＡ機器の節電	1	2	3	4	5	6
ｴﾚﾍﾞｰﾀ･ｴｽｶﾚｰﾀの使用抑制	1	2	3	4	5	6
断熱材や複層ガラス断熱の導入	1	2	3	4	5	6
太陽光発電等、自然エネルギーの導入	1	2	3	4	5	6
その他（　　　　　　　　）	1	2	3	4	5	6

E-3　以下の項目について､貴建物において今後どの程度エネルギー消費量が増減するとお考えになりますか。
それぞれのエネルギーの使用用途について、当てはまる番号一つに○を付けて下さい。

	大幅な削減が可能	微少な削減が可能	ほとんど変わらない	微少な増加となる	大幅な増加となる
暖房用エネルギー	1	2	3	4	5
冷房用エネルギー	1	2	3	4	5
照明用エネルギー	1	2	3	4	5
給湯用エネルギー	1	2	3	4	5
エレベータ･エスカレータ用エネルギー	1	2	3	4	5
ＯＡ機器用エネルギー	1	2	3	4	5
その他（　　　　　　　　　　　）	1	2	3	4	5
建物エネルギー全体として…	1	2	3	4	5

E-4　貴建物において設置されている省エネルギー対策装置の有無について、当てはまる番号一つに○を付けて下さい。

対策の方法等	装置の概要	あり	なし	不明
デマンド制御装置	使用電力のピークを制御するため、警報や負荷遮断を行う装置	1	2	3
コジェネレーション	電気を発電すると同時に熱を発生させ利用するシステム	1	2	3
照明自動点滅	太陽光センサ方式、人感センサー方式、タイムスケジュール制御方式など	1	2	3
高効率照明	インバータ蛍光灯、Ｈｆ（高周波）インバータ蛍光灯など	1	2	3
蓄熱槽	熱を一時的に蓄熱槽に貯蔵し、必要なときに熱を取り出すシステム	1	2	3
外気冷房	外気導入量を増大させて冷房負荷を低減させる方法	1	2	3
熱回収ヒートポンプ	冷房による排熱を給湯・暖房用にヒートポンプで熱回収する装置	1	2	3
全熱交換器	取り入れ外気と排気の間で顕熱、潜熱両方を熱交換回収する装置	1	2	3
CO_2制御	外気負荷を低減するためにCO_2濃度で外気取り入れ量を制御する方法	1	2	3
変風量（ＶＡＶ）	負荷に応じて送風量を変えることにより冷暖房能力を調整する方法	1	2	3
変水量（ＶＷＶ）	負荷に応じて給水量を変える方法	1	2	3
節水機器	節水コマや、水流し音発生装置等	1	2	3
雨水利用の有無	雨水を貯留し雑用水等に利用する	1	2	3
排水再利用の有無	排水を処理し雑用水等に再利用する	1	2	3

質問は以上です。ご協力ありがとうございました。